

G.Gordon and L.Gordon

# The sky will be blue



## **About This Book**

This book tells the reader in popular form just what dust and gaseous impurities consist of; how they originate in metallurgical works, what a grave danger they are to all living things on the Earth, and how man protects himself and his habitat from them. A picture is drawn of the future when metallurgy will be free of dust and harmful gases. Original drawings supplement this interesting narrative. The book is intended for general public.

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Т. М. ГОРДОН, Л. М. ГОРДОН

# **БЫТЬ НЕБУ ГОЛУБЫМ!**

«Металлургия» · Москва

**G. Gordon and L. Gordon**

# **The sky will be blue**

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## PREFACE

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Air, one of the most important constituents of our environment, is the basis of our life and economic prosperity. The damage caused by air pollution is enormous; it greatly reduces the gross output of agriculture and forestry, decreases operating efficiency, increases the sick rate of the population, deteriorates the quality of production, increases maintenance and breakdown expenses of public utilities. The prevention of air pollution is one of the main tasks confronting many branches of industry, in particular, metallurgy.

In recent years the interest of the public in the problems of environmental protection has appreciably grown as witnessed by the numerous national and international publications, conferences, meetings, symposia which deal, as a complex whole, with topics concerning the spreading of pollutants, waste-free technological processes or those with very little waste, monitoring the state of the environment. It is now clear that nature which only a few decades ago was capable of coping with industrial wastes is now in need of our help.

Waste-free technology is the ultimate goal of all the measures aimed at the prevention of atmospheric and water pollution. But in the meantime a great role is still played by various cleaning equipment including gascleaning and dust collecting apparatus. They



have been developed and perfected during a long enough time now to secure our well-being. Although they are rather expensive, their cost is economically justified. Besides keeping millions of people healthy, we save for our industries many valuable raw materials and products. From this point of view cleaning equipment will not lose its significance even in waste-free technology.

This book discusses in popular form the problems of environmental protection, tells us how these problems are solved by metallurgists, i.e., by those engaged in that field of industry which due to the nature of its technological processes often substantially contributes to atmospheric pollution. The book will be interesting reading for young people and for workers in many industries.

I. V. Petryanov-Sokolov,  
Member of the USSR Academy of Sciences

Perhaps, looking through this book  
You'll say  
How murky  
How hazy is the sky!—  
This happens too ...  
But just the same  
I'll show you a sky  
That is clear and blue.

From the poem *The Clear Sky* by L. Martynov

## **ONE PLANET FOR ALL**

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### **(Instead of an Introduction)**

The scientific and technological revolution has given rise to many problems and perhaps the most vital of them is the relationship of man to his environment. Everything essential for his life man takes from nature, sometimes unhesitatingly and ruthlessly interfering with the natural processes. Compare the maps of the present century with those of the century that has just passed and you will see blue spots indicating new lakes and artificial seas, marks signifying canals, and points showing the location of cities in regions previously little known. Still in his time Engels warned us not to be deluded by our victories over nature which avenges itself for every such victory; that though it is true that in the first instance we would get what we expected, in the second and third instance altogether different and unforeseen consequences might ensue which very often cancel the primary gain.

The twentieth century has shown how prophetic this warning has proved to be. The natural resources have been found to be not as inexhaustible as was previously supposed. Despite the great blue expanses there is not enough fresh water, and the boundless sky does not save us from the lack of clean air. The protection of nature, man's environment, against the negative consequences of his

activities has attained social significance because not only is the health of individuals threatened, but also the life of mankind as a whole. This has become a global problem because the atmosphere is one for all; winds and clouds know no boundaries; the same rivers carry their waters through different countries; so the problem can be solved only by the joint efforts of all nations.

At the present time in many countries throughout the world hundreds of institutes are making long-range forecasts, estimating for how many generations the resources of coal and oil, of ferrous and non-ferrous metal ores will last; are searching for new sources of energy and new materials. And in the meantime... As yet metal remains the main material, so, unfortunately, metallurgists, whether they want to or not, are the leading contributors to pollution of the environment, in particular, to air pollution.

The principal course for preventing the adverse effects of industry on the environment is by improving technological processes, and creating closed technological cycles. Nature with its breathing plants affords a marvelous example—a giant photosynthetic factory operating without wastes. The plants covering the Earth annually yield 100 billion tons of biomass and the same quantity of oxygen. But man in his activities has not been able to avoid wastes yet. There is a growing amount of domestic wastes, the treatment and utilization of which present a great problem, and technological wastes are not as yet a thing of the past—only a few processes dispense with them. We will not dwell at length on domestic wastes because it is industrial wastes that concern us now. Are they really so inevitable? Let us consider, for example, whether waste rock in mines and pits, waste water and dust and gas emissions can be called wastes. We doubt it; theoretically there are no wastes that cannot be utilized. They may be considered as intermediate products resulting from unfinished production and they can all find application.

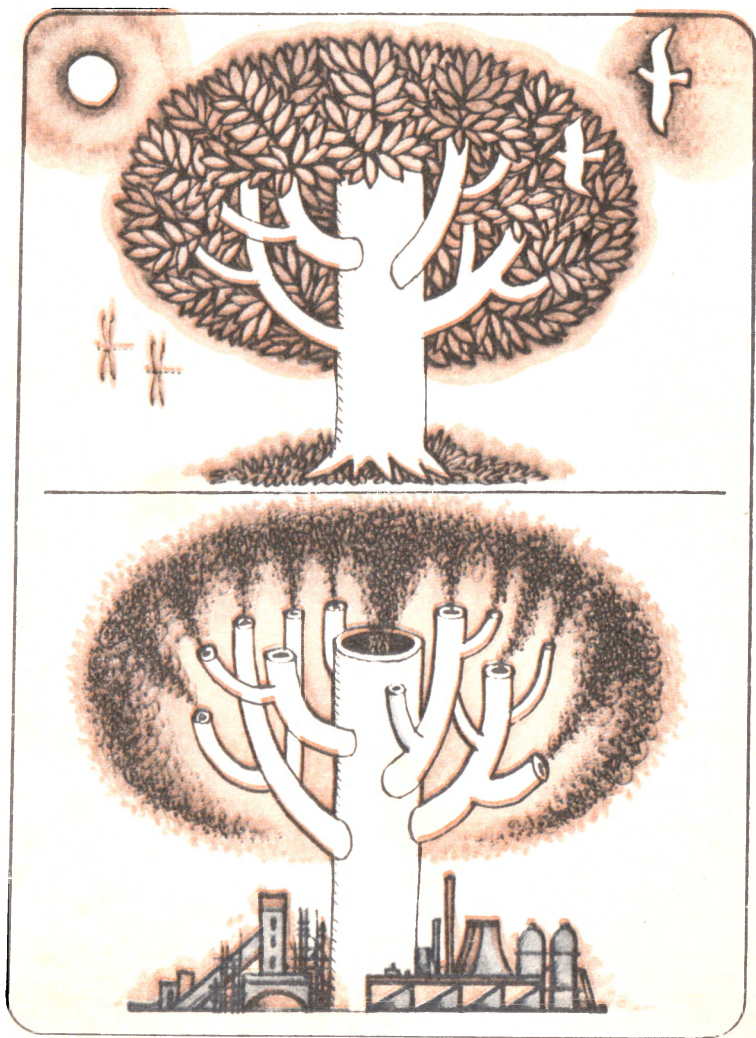
The metallurgical industry, in this respect, has already had some experience: for example, blast-furnace gas is used as fuel; slag, for producing building materials; gases generated in the manufacture of copper, for producing sulphur and sulphuric acid. Scientists have



also proved that slime (substances insoluble in waste water), in particular, the slime of gas-cleaning apparatus of steel-smelting furnaces can be a valuable raw material for the chemical and building industries. In the reprocessing of polymers and plastics, slimes can be used instead of ferrous powders; and in the production of building materials, as pigments. Coloured silica brick from slimes, for example, is an excellent product. The utilization of wastes, however, is not a cardinal solution of the problem. There aren't, as yet, any completely closed processes. The direct reduction of iron and oxygen-flash smelting of copper can be considered, for instance, to be important landmarks on the way to the creation of such processes. These industrial cycles have a very promising future.

Well, in the future there will be continuous and waste-free industries. Scientists and engineers are now working on this. At the same time, processes are being perfected for purifying wastes, in particular, gas emissions, to free them from harmful ingredients. It cannot be otherwise. These processes can become links in the chain of continuous metallurgical cycles.

In recent years gas-cleaning and dust-collecting have made great advances. Additional solutions have appeared: new filters have been designed, in particular, filters with wire cloth for cleaning gases at temperatures of 500-600°C; methods for cleaning gases in strong electric fields have been worked out, and methods for suppressing the ejection of gas and dust from metallurgical plants, to name only a few of them. In this book we want to tell you about gas-cleaning and dust-collecting and many other interesting and important things connected with it.



## **ELIXIR OF LIFE**

### **Natural Balance on Earth**

Life on Earth originated approximately 3-3.5 billion years ago and since then living things began to take part in the geochemical processes on the planet, contributing their share to the habitat necessary for the survival of life. An exchange of materials set in between the organic and inorganic world which continues to this very day and will only cease when all living things disappear. This is the essence of the teachings about the biosphere, which appeared in the twenties of this century. The founder of this doctrine was V.I. Vernadsky whose works now form our basis of nature protection.

Biosphere is not a new word. This term was used in the 19th century to signify the thin outer part of the Earth inhabited by living organisms. It was considered to exist independently along with three other spheres: the atmosphere (air), the hydrosphere (water) and lithosphere (Earth's crust).

V.I. Vernadsky too regarded the biosphere as the outer part of the Earth, constituting life's natural habitat. However, from his point of view, in the first place the limits of this sphere are much wider than was earlier assumed. The biosphere stretches upwards 10-15 kilometers, occupying the lower part of the atmosphere, the troposphere, and descending 8-10 kilometers into the ocean and 2-3 kilometers below the surface of the earth. These are the boundaries inhabited by living things. In the second place, the living things, i.e., animals, plants and microorganisms, are continuously interacting with each other and the environment: air, water and the Earth's crust. And in the third place, the products of their interaction such as "biogenous matter" (humus, peat, coal) and "biologically inert matter" (sedimentary rock, the near-Earth atmosphere, etc.) are also components of the biosphere since they were produced by living organisms in the past.

The elementary unit of the biosphere, biogeocenosis (the term proposed by V.N. Sukhachev), is a community of plants, animals

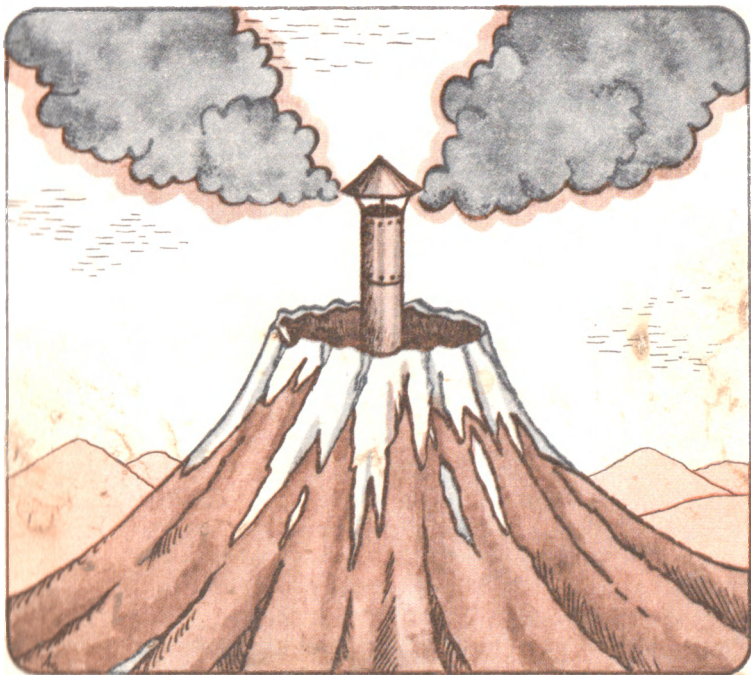
and microorganisms which are in constant interaction with the atmosphere, the soil and hydrological conditions. Close to the meaning of biogeocenosis is the term "ecological system" or "ecosystem".

Biogeocenoses, or ecosystems, can be on different levels and of different size. The global ecosystem of the Earth, i.e., its biosphere is made up of smaller continental and oceanic systems. Still smaller ecosystems are the large forests, deserts, plains, mountain ranges. But in comparison with a small lake or ravine overgrown with weeds, they are gigantic. Every ecosystem is characterized by a balanced, harmonious functioning determined by many factors. Try to remove or change any of them and harmony will be upset. Air, the gaseous component of the biosphere, in this sense is not an exception. Should foreign matter appear in it, forests will perish, rivers will become shallow and dry up, and animals will go off or become extinct.

Such foreign matter, air pollutants in particular, mainly affect those ecological systems whose territories are invaded by industrial plants. The air in the vicinity of most power stations, as a rule, contains as much as 0.1% of sulphur dioxide. At such a concentration, plant life in general is impossible. Near aluminium plants, fluorine emissions in the form of gas and dust fatally affect nature. They cause pine needles, for instance, to grow yellow and fall from the trees which die because of the lack of fresh air. Many such examples can be cited.

But what happens if the concentration of harmful substances in the air is not high enough to cause the death of plants? In this case, their photosynthetic power, i.e., their ability to produce carbohydrates and liberate oxygen by the action of sunlight, is diminished. It is known that an average-size tree can supply three people with oxygen. No wonder the plant world is called the "green lungs" of the planet.

The "green lungs" have not an easy time now that the demand on oxygen has grown considerably. Besides man and animals, its consumers are now rockets, planes, automobiles, and industrial



plants. Every year the quantity of oxygen in the atmosphere decreases by several billion tons.

At the same time the amount of carbon dioxide in the atmosphere has increased. Judge for yourself: only thirty years ago we breathed air that contained 30 parts of carbon dioxide in 100 000 parts of air; now this proportion has increased to 33.5 parts, and by the year 2000, as believed by a number of scientists, it may grow to 40 parts. The ones to blame are the consumers of oxygen—they are the main producers of carbon dioxide, the product of fossil fuel combustion.

There is still no agreement of opinion whether the temperature of

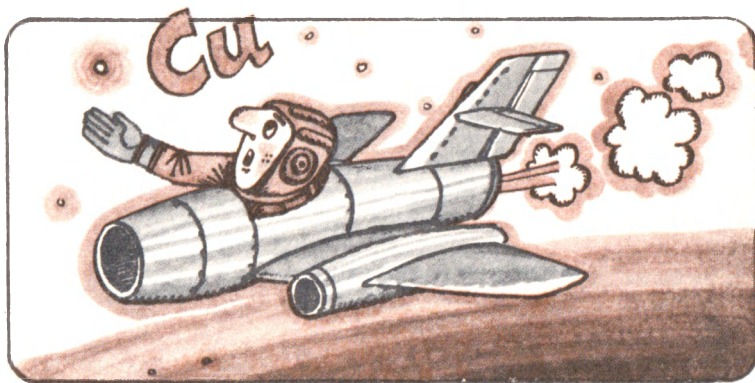
our planet will rise or fall as a consequence of the carbon dioxide increase. Some scientists foresee a time when the ice caps of the Arctic and the Antarctic will thaw, the oceans will swallow up thousands of islands and man will be deprived of enormous mainland territories. Others prophecy a new ice age. Still others deem that no climatic changes should be expected because the increase in airborne dust will neutralize the "green-house" effect produced by carbon dioxide, which blankets the Earth, not allowing the heat to escape into outer space.

Time will show who is right. One thing is clear—the balance of gases which remained unchanged up to the industrial revolution has now been upset so drastically that it cannot be restored by all the green plants on land and in the ocean.

Our relations with nature are contradictory and complicated: we are simultaneously its conquerors and its victims. Our needs are great. We require clean air and water, food, clothes and houses. We want to move and to think quicker. Every year mankind needs more fuel, metal and building materials. And all this is so, not only because of the growing population, but also because of the growing prosperity of people. And we can hardly be expected to deny ourselves comfortable cars or travelling by plane for the sake of clean air and other natural blessings. There is no way back for mankind. Armed only with the accomplishments of science and technology can man protect his habitat, one of the most vital components of which is air.

### **Air Cocktail**

You know, of course, that dry air is a mixture of gases consisting of 20.9% of oxygen, 78% of nitrogen, 0.03% of carbon dioxide and minute amounts of hydrogen, argon, helium, krypton, xenon, radon, and that a person cannot survive more than five minutes without air (though he can live five weeks without food and five days without water). It is virtually the elixir of life! But do you know that pure air of this composition hardly ever exists in nature and that actually air is a mixture of gases in which tiny solid and liquid



particles are suspended; in other words, air is an aerosol.

Where do these pollutants come from? To be more exact, why and how does air come to be such a system? Primarily, because it is part of the biosphere and the particles floating in it result from the interaction of air and its other constituents: water, soil and living things.

Dispersed particles are constantly supplied by natural processes (though in our times they are not the chief source). It suffices to say that during intense volcanic eruptions great masses of minute solid and liquid particles are thrown forth with the gases to a height of 20 kilometers; they can remain in the atmosphere for weeks. After an eruption of the Krakatoa volcano, for example, particles of 0.002 mm across, i.e. much smaller than grains of flour or powdered milk, did not settle down for several years. Forest fires yield minute solid particles of smoke that spread out over tens and hundreds of kilometers and thousands of such fires occur every year. Large quantities of particles fill the air due to soil erosion and the resulting sand storms. Sea "dust" (spray) caused by the surf rises to a height of a few kilometers and on evaporating in dry air leaves sea salt and mineral particles in it. Even over the island of Tasmania, lost in the ocean, in the atmosphere (at a height of



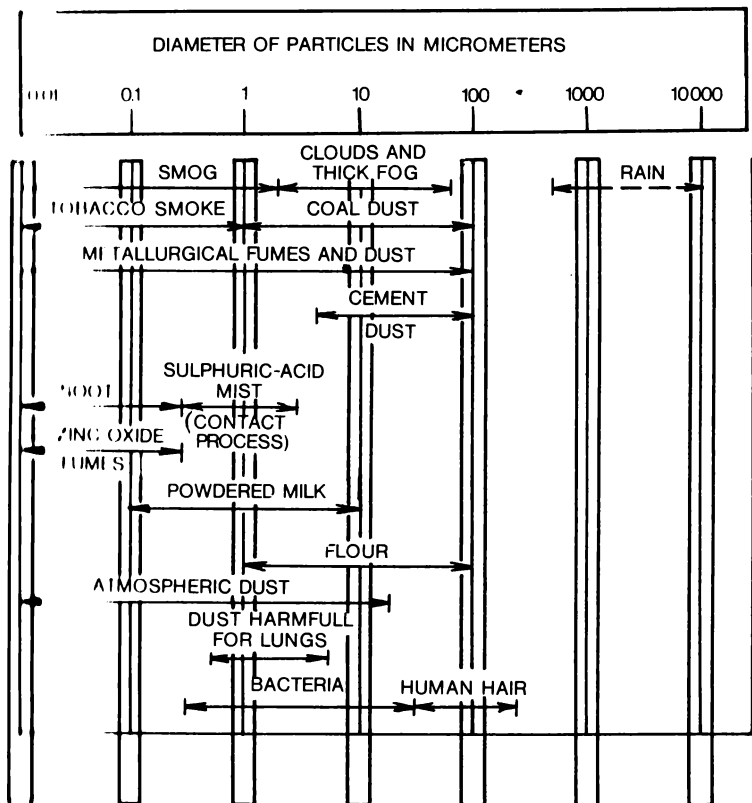
2 000 m) particles were found that proved to contain copper. Other oceanic aerosols can also originate in this way.

Daily 10 000 tons of cosmic dust falls out onto the Earth. Where this comes from is still a mystery: perhaps it appeared as the result of the activity of the Sun or originated in zodiacal nebulae. There are also plant aerosols. Dispersed particles emitted by plants can be liquid (evolved during growth) and they can be pollen grains produced in the period of blooming. The spores of mushrooms and ferns can be found 1 600 m above the ground. And, finally, mists, fogs, clouds and rains are also aerosols whose basic medium is air. They can be called aqueous aerosols.

You see now how vast and multi-faced is the world of aerosols, figuratively speaking, "air cocktails". They differ not only in their content but in the size of the particles (see the drawing); that is why they are respectively called drops, spray, fog, mist, dust or smoke. Besides, the composition of the air itself can change if, for instance, volcanic gases or gases resulting from the vital functions of living organisms are added to it. But this is still not all. Up to now we spoke only of natural aerosols, but how many are produced unnaturally by industrial plants, cars and other means of transport.

To realize that this is so it is not even necessary to know the data of the hydrometeorological service which regularly takes air samples in large cities. It is enough to stop at any street corner to be aware of the smell of burned gasoline. How different it is from the fragrant smell of grass or the freshness of sea air! On a world scale, 40% of all air pollution is due to auto transport. The remaining 60% is shared by various branches of industry among which, as we already know, one of the leading places belongs to metallurgy. Although the technological processes may be radically different, they have one thing in common—they all use energy supplied by coal, oil, natural gas and other fuel. We also burn fuel to heat our houses, to operate powerful machinery or to drive motor vehicles.

Combustion processes are the main source of gases that pollute the atmosphere and the chief "devourers" of oxygen. Consider these figures: to travel 1 000 kilometers, a car consumes as much oxygen



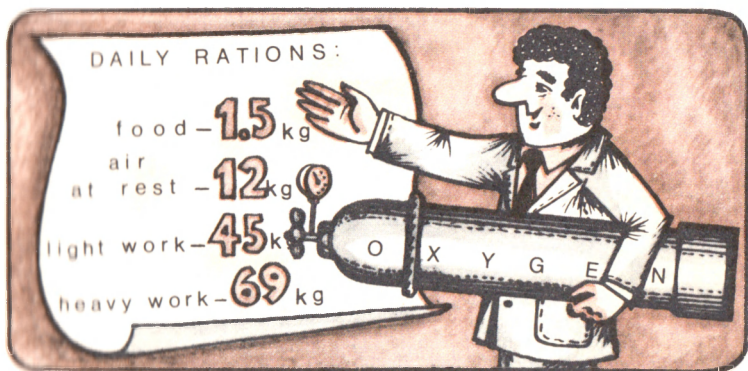
as one adult needs to carry on his vital functions during a whole year, a jet liner to cross the ocean consumes 50-75 tons of oxygen in 8 hours whereas for the same period of time such a quantity of oxygen is expired by 25-50 thousand hectares (1 ha – 10 000 square meters) of forest.

In complete combustion of fossil fuel, carbon dioxide and water vapours are released into the air and, in much less amounts of

course, oxides of sulphur and nitrogen. But only if combustion is complete. This, unfortunately, is not often the case. When the conditions of combustion are not perfect: the fuel and oxygen are not mixed well, the draft in the flue system is not sufficient, the fuel used does not correspond to the design of the furnace, then combustion is incomplete and toxic carbon monoxide and other gases just as harmful are emitted into the atmosphere. For example, to completely burn 1 kg of coal requires 15 kg of air—the amount one person needs daily. If there is not enough air, carbon monoxide (CO), containing only one atom of oxygen, is produced instead of carbon dioxide. Man is not indifferent to the carbon-dioxide content in the air, because if it increases the oxygen content diminishes. As to carbon monoxide, it is very toxic: it blocks the supply of oxygen to the tissues of the human organism.

Another component of flue gases is sulphur dioxide (previously mentioned by us) or, as it is called, sulphurous anhydride ( $\text{SO}_2$ ). And if the evolution of carbon monoxide can be avoided by regulating the combustion process, it is impossible to avoid the formation of sulphur dioxide in this way. It is produced when oxygen combines with the sulphur contained in the fuel, minerals and ores. Coal, for example, contains from 0.5 to 5.0% of sulphur. There is still more sulphur (tens of per cent) in the raw materials of non-ferrous metallurgy: copper pyrites, lead ores, etc. Under favorable conditions sulphur dioxide combines with oxygen, forming hygroscopic sulphuric anhydride ( $\text{SO}_3$ ) which in its turn unites with water to form sulphuric acid which does not spare green plants, man or things made by him.

Still another gas inevitably present in many industrial gases is the oxides of nitrogen that are produced by furnaces and motor transport. Nitrogen oxides are most intensively formed in the internal-combustion engines of automobiles, the number of which in the world today amounts to 300 millions. In accordance with prognoses, the number will grow in geometric progression. Naturally, the concentration of nitrogen oxides will increase proportionally. How these oxides affect the urban climate (such a term has recently appeared) we will record below.



The boiler rooms of dwellings, furnaces of industrial plants and power stations, internal-combustion engines of automobiles also pollute the air with unburned hydrocarbons or oxidized substances, soot (unburned particles of coal) and, finally, dust and fumes.

Annually, the atmosphere is polluted by more than 200 million tons of carbon monoxide, more than 50 million tons of various hydrocarbons, approximately 146 million tons of sulphur dioxide, 33 million tons of oxides of nitrogen, 200-250 tons of dust, 120 million tons of ashes and soot. These figures do not only represent the products of fuel combustion but also the emissions of harmful gases and dust which accompany many industrial processes.

The gases and airborne particles are not "indifferent" to each other. They participate in all kinds of chemical reactions: photosynthesis, oxidation, reduction, polymerization, condensation and catalysis. Sometimes this leads to the formation of substances that are even more toxic.

It might seem that the hundreds of millions of tons of pollutants emitted annually into the atmosphere, amounting to less than one ten thousandth part of one percent of the weight of atmospheric air, are only a drop in the ocean. But that is far from the truth. The point is that, in the first place, the amount of substances polluting the atmosphere eventually accumulates; in the second place, the

distribution of pollutants is not uniform and in certain places their concentration is now inadmissibly high; and in the third place, even very small concentrations of certain substances are dangerous.

### **Smog Alarm**

A dense mist hung over London. The city which the day before still smiled cheerfully in the sunshine began to suffocate. People began to show symptoms of lung trouble. The ones to suffer most from asphyxia were children and persons over fifty years of age. Five days of thick fog turned out to be disastrous for Londoners, carrying away 4000 lives.

The great London catastrophe of 1952 was not the first one to pose the problem of air pollution. In 1930 it was the inhabitants of the valley of the river Maas in Belgium who were the victims of a similar though less drastic disaster, and in 1948 the inhabitants of the city Donora in the state of Pennsylvania, USA. Also ill-famed are the American city Los Angeles and many other cities in Japan and other countries whose skies are often overclouded by a haze that obstructs the sun rays.

No wonder the meteorologist Morris Neuerberger of the University of California sounds anxious and pessimistic when he points out that a stifling fog would eventually envelope the Earth and civilization would disappear. It would perish not as a result of a cataclysm but because of gradual suffocation due to its own wastes. Doctor Richard Prindly, the assistant secretary of the US Department of Health and Welfare, seconds him in saying that it has now become a question of life and death; that cases are known where air pollution has killed people and in the course of our progress the number of such cases would grow.

We do not propose to discuss the judgement of the overseas' scientists. Their alarm for the future of the planet is quite natural. Nevertheless, there are no grounds for gloomy pessimism.

Let us return to the events in London in the autumn of 1952. The city authorities then announced that only the fog was to blame for all, failing to report that in those memorable days the content of

unhealthy pollutants in the air of the British capital considerably exceeded the permissible one. The catastrophe was caused by a smog—a complex physical and chemical phenomenon, the essence of which is disclosed partially by the word itself, coined by an English physician, in which he combined the words *smoke* and *fog*. Consequently, smog is primarily a mixture of fog and smoke, the deformed offspring of nature and civilization. Concentrating industrial and transport emissions, smog lives by its own laws.

From time immemorial, weather forecasts are made according to the way smoke rises from stacks. If it goes straight up, clear weather is to be expected; if it hangs low it means rain. These signs may prove to be correct; only it never occurred to anyone that the cause was the effect, and the effect the cause. Actually it is a matter of the relationship of the behavior of smoke and the state of the atmosphere. Meteorologists have defined this relationship more exactly. Without going into their investigations in detail, we will only dwell on one natural phenomenon which is directly connected with the generation of smog, namely inversion of the usual temperature gradient in the atmosphere. Whereas normally the temperature decreases with height, in inversion it increases. Normally, if the drop in temperature over a city is greater than one degree Celsius per 100 meters of height, the warm bottom layers of air move upward, carrying away the harmful gases. The atmosphere of the city is refreshed.

In temperature inversion, the heavy cold air saturated with industrial and transport emissions remains near the ground, compressed under a dome of warm air. For example, in the city of Donora that underwent a smog catastrophe, the inversed layer was only 300 meters above the ground (about as high as low clouds on a rainy day).

Thus, the first indispensable participant of smog catastrophes is temperature inversion. Its “accomplices” can be the local topography and climatic conditions peculiar to one or another place, and even the sun which gives rise to photochemical reactions.



In London a smog always arises when the city is enveloped in a thick fog. That was the case in 1952, 1956, 1957 and 1962. The British capital was always famous for its fogs, but they only became a serious danger to life in the middle of our century. Scientists have come to the conclusion that sulphur dioxide ( $\text{SO}_2$ ) should be chiefly blamed for the tragic events. During the greatest London smog the concentration of  $\text{SO}_2$  was six times the usual content. A similar yellow-brown mist ("black smog") brought disaster to the valley of the Belgium river Maas and to the city of Donora.

Smogs hang over Los Angeles 270 times a year. Here, however, it is of a different kind: a haze overclouds the city while the sun is shining brightly. Temperature inversion also takes place, but it is due to the surrounding mountains and that the city is situated in the eastern outskirts of a large area of high atmospheric pressure, called the Pacific anticyclone. The air is usually calm and quite warm above the earth, but near the ground it is cooled by the California Current.

The riddle of the Los Angeles smog was solved in the fifties of our century by an American scientist, Haagen-Smith. He detected that there was a direct dependence between the content of ozone ( $\text{O}_3$ ) in the air and the



effect of sunlight: at night the ozone content of the air was much less than in the daytime. Ozone is formed as the result of the decomposition of nitrogen peroxide ( $\text{NO}_2$ ) to nitric oxide (NO) and nascent oxygen (O). A great amount of nitrogen peroxide is set free by more than 800 thousand automobiles simultaneously moving in the state of California in the rush hours. Atomic oxygen combines with molecular oxygen to form ozone which in its turn regenerates nitrogen peroxide that is ready to react again. It may seem that under these conditions ozone cannot be accumulated in the air. But that is not so because hydrocarbons also react with nitrogen peroxide. Ozone is accumulated in the air and it is the ozone, together with other substances formed by chain photochemical reactions, that gives rise to the toxic fog that irritates the mucous membrane of the organs of sight and smell, and of the respiratory tract.

A black smog affects man in the same way, although the reactions that occur in it are not the same. Smog indiscriminately corrodes everything: plant cells, rubber and fabrics, nylon stockings, and historical buildings and monuments. It has become known not only in England and America but also in Italy and Japan where more than half of the population has not seen a blue sky for a long time. In Tokyo in 1966 a "smog alarm" was proclaimed for 154 days. In Los Angeles the local authorities issued instructions for the population with rules for behavior at times of smogs.

The natural processes cannot be stopped. It is impossible to make the California Current flow backwards or to protect the British Isles against fogs, but everything that can be done should be done to keep the air of industrial cities clean.



## **BIRTHPLACE—METALLURGICAL WORKS**

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### **Forced to be First**

It is not by chance that the ancients considered the God of Fire to be the patron of metallurgy—and it is not important that the Greeks called him Hephest while the Romans called him Vulcan. What is important is that they both understood that metal cannot be obtained without fire. Since then much has changed in metallurgy: the processes for obtaining metals, the design of the plants and the scale of production. Man has learned how to obtain not only iron and steel but also tens of other metals unknown until a relatively short time ago, including aluminium, titanium and many others. Methods of extracting metals with the aid of liquid media have appeared (so-called hydrometallurgy). But the main processes, just as in ancient times, are still those connected with the utilization of high temperatures—“firing” processes, otherwise called pyrometallurgy (“pyro” is the Greek for fire). Such methods are used to obtain 100% of the iron, steel and lead; 80% of the copper, and over 40% of the zinc.

Ancient artisans saw their patron god covered with soot and dust, which corresponded to the actual conditions under which metals were smelted at that time, and as the principle of smelting has not changed substantially since then, the generation and emission of dust and gases still invariably go with it.

Let us take, for example, plants that produce crude copper. The lot of copper smelters is unenviable: they have to utilize ores that contain only 0.5-0.6% of copper, i.e. five-six kilograms per ton. Moreover, the copper is present in the ore not in the pure form but as salts of hydrosulphuric acid (sulphides). An intimate union that is hard to break apart! It is true that the ore is preliminarily enriched to obtain concentrates containing up to 18-25% of copper, but still the amount of sulphur remains great: from one and a half to two times more than copper itself. Besides copper and sulphur, the concentrates contain iron, lead, zinc, arsenic and other elements.

They are all important for industrial use and must be isolated in smelting. As a result one plant producing, on an average, 125 thousand tons of copper a year by smelting in a reverberatory furnace (a method that is still widely practiced) yields annually, besides the basic metal, more than two billion cubic meters\* of gases (sulphur dioxide among them) and ejects 43 thousand tons of dust. A "train of dust" more than seven kilometers long! A weighty argument for the necessity of gas-cleaning and dust-collecting, isn't it? It is obvious that gases and dust are by-products of the metallurgical industry; in most cases, however, it is impossible to avoid them in the process of obtaining metals.

It is not by chance that metallurgy is called high-temperature chemistry: the isolation of the desired metal from its "co-travellers" by means of pyrometallurgical processes takes place on heating as a result of chemical reactions. Of great importance are the oxidizing reactions which are impossible without air supply. The oxygen in the air combines with the components of the furnace charge to form oxides of sulphur and other volatile and low-melting oxides of the charge components, and thus frees the metal that is being smelted out. The greater the amount of air supplied, the greater the quantity of gases evolved.

Let us consider once more the aforementioned copper works. Because of the large amount of sulphur, copper is extracted in the reverberatory process in three stages. First the sulphur is partly burned in a roasting furnace with a fluidized bed where calcine is obtained. Then the calcine is smelted in a reverberatory furnace to form copper matte containing 40-45% or more of copper. And, finally, air is blown into the matte in a converter to completely remove the sulphur. The input of air and the amount of gases evolved differ in the different plants. In roasting furnaces, it is 3 800 cubic meters per one ton of copper, in reverberatory furnaces 8 000, in converters 4 800. The record figure for reverberatory furnaces is connected not only with the air consumption required by the

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\* Henceforth we use the volumes referred to the standard temperature and pressure (STP): 0°C and 1 atm = 101 325 Pa (760 mm Hg).

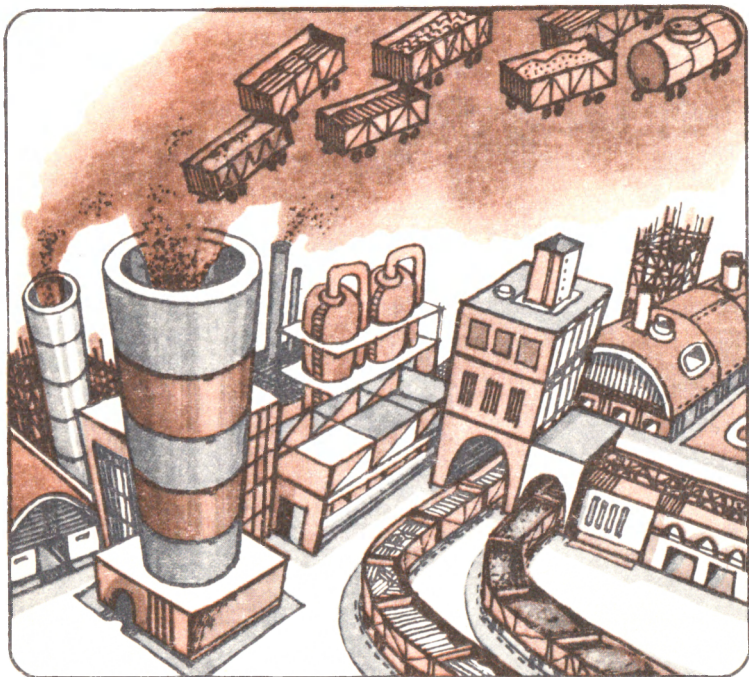
technological process, but also with the special features of the furnaces: in contrast to roasting furnaces and converters. reverberatory furnaces have many charging inlets through which atmospheric air is additionally drawn in.

The flow of hot gases having a temperature over  $1000^{\circ}\text{C}$  and more entrains minute particles of the furnace charge, the vapours of metals and their compounds and emerges in the form of an aerosol. And although one cubic meter of gas usually contains from 10 to 50 grams of dust (depending on the design of the furnace and its operating conditions) the total quantity of dust per one ton of copper is quite imposing—342 kilograms. Multiply this figure by the output of the works (125 thousand tons of copper a year) and you will get the 43 thousand tons mentioned above. And this is not ordinary dust but “gold” dust. It contains 6000 tons of copper—about 100 railroad cars. The gases that carry this dust are also rich. The amount of sulphur contained in them, is enough to produce 650 thousand tons of sulphuric acid.

It is appropriate to ask: “Can it be that all this wealth is just gone with the wind?” The answer to this question constitutes the essence of the problem of environmental protection and rational utilization of natural resources.

Of course, not all the gases and dust generated in metallurgical plants are emitted into the atmosphere. The gas-cleaning and dust-collecting services come to the aid of metallurgists. If this were not so, the amount of sulphur dioxide emitted by copper-smelting works alone would be enough to poison the whole of mankind. Just the same 97% of the sulphur contained in the atmosphere in the Northern Hemisphere is emitted by metallurgical works, heat and power plants, and transport. No wonder there are frequent acid rains.

From the network of the gas-cleaning and dust-collecting service of copper works with traditional smelting processes, only 4.5% of the dust and 12% of the sulphur evolved, i.e., about 35 thousand tons a year escape into the atmosphere. From this amount of sulphur in the air it would be possible to obtain 88 thousand tons of sulphuric acid. All that would be needed for this would be



a temperature inversion and high atmospheric humidity. Then the highest smoke stacks would not be capable of dispersing the sulphur dioxide in the air. It is a lucky thing that such exceptional meteorological conditions do not last for a long time nor can they arise everywhere. Nevertheless, the damage caused by dust and sulphur are very great. In the USA in 1970, the total damage due to the emission of dust and sulphur amounted to 15 billion dollars!

Of course, the 88 thousand tons of sulphuric acid could be obtained industrially if the gases from the reverberatory furnaces did not have to be discarded. But these gases contain only 1.2% of sulphur dioxide. That is very little. Certain features of design and

technology hamper the production of sulphuric acid from such raw material.

The conclusion that involuntarily suggests itself is that the time has come to change the conditions that cause the high generation of dust and gases and their emission into the atmosphere. These problems now occupy the minds of scientists and technologists working in this field. But that is another story.

Now let us return to a metallurgical works. This time it can be any kind. Hundreds of thousands and even millions of tons of raw materials arrive at each works. They are unloaded, sorted, transported to the plants and everywhere dust is generated. How much? It is hard to estimate the quantity. In any case, many times more than is generated when a dump truck is unloaded and you always try to avoid such a truck, afraid not of the load itself but of the cloud of dust surrounding it.

The amount of dust is not less in the places of preparatory operations, such as crushing of large-sized material or, on the contrary, lumping of small-sized material, drying of raw materials, and many others. Here gases are also evolved. However, modern metallurgists, unlike their ancient colleagues, do not work in an atmosphere of dust and gases. The metallurgical plants, transportation facilities, plants for preparatory operations, and the shop premises are equipped with powerful ventilation systems that draw off the gases. And, although these so-called ventilation gases are less contaminated than the process gases formed directly in the plants, they too, as a rule, are purified, primarily because many millions of cubic meters of these gases escape into the atmosphere every hour.

But in spite of the efforts of metallurgists and chemists, the iron and steel industry accounts for 25.6% of the total amount of dust emission and 17.6% of the total emission of sulphur dioxide. Nonferrous metallurgy is more "miserly" as concerns dust (2.8%) but more "generous" as concerns sulphur dioxide (18.5%). Very eloquent figures, aren't they? It is these figures that secured for the metallurgical industry the first place among the violators of our well-being.

## **Distant Reconnaissance**

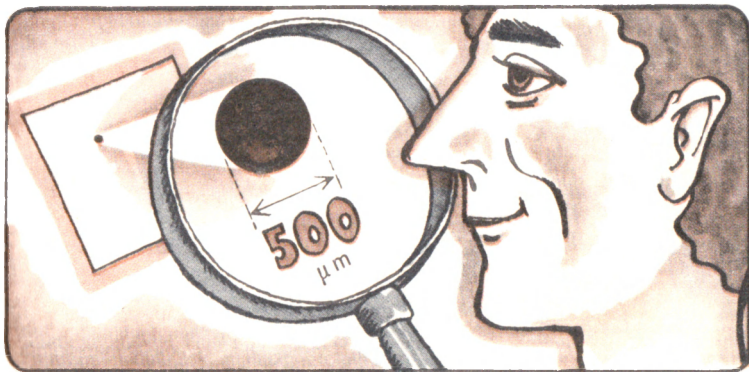
When preparing to take the offensive, the military commander sends out a reconnaissance party (scouts) over to the enemy region to find out the strength and arms of the opponent. Whether or not the battle will be won depends on the information brought back. The dust-collecting service has its own "scouts" for providing data on the dust content and, in particular, its particle-size distribution. And the operation of the dust-collecting apparatus (how effective and economical it will be), the proper choice of their design and capacity and, finally, the sanitary conditions in the surrounding atmosphere depend on this data.

In the army one of the reliable ways of getting authentic information is to capture an identification prisoner or "identifier". In the dust-collecting service such "identifiers" are the samples taken of dust-laden gas and dust. Of course, it is less dangerous to take samples than to capture an "identifier" but they are, none the less, just as valuable; and sampling is not as simple as it seems, because the particles involved are only several micrometers in size. It is known that one micrometer is equal to one thousandth part of a millimeter. But this is difficult to comprehend; try, if you can, to divide an ordinary typographic point into 500 parts (the diameter of one dot in print equals 500 micrometers). To do this it will be necessary to use instruments and tools indispensable to modern skilled craftsmen for applying microminiatures on rice grains or human hairs.

And the point is not only that the particles are microscopic in size but that such minute dimensions determine their properties which differ in many ways from the properties of macroparticles. Large particles on collision jump away from each other like billiard balls, whereas dust particles in this case conglomerate to form loose clumps. Macroparticles rebound from the surface they hit, while dust particles settle on the surface. The adhesive forces of microscopic particles are very great indeed.

Microparticles have other properties that distinguish them from macroparticles. They readily react, in particular, to form oxides,





and are even capable of spontaneous combustion. Moreover, explosion of dust clouds can take place. However, it is not these properties but their ability to conglomerate and adsorb that affects the quality of the samples taken and determines whether they are representative or not.

Conglomeration and settling are processes that occur during the entire time the aerosol exists. They can take place any number of times because the dust particles are in continuous agitation. Recall how they whirl like a swarm of midges caught in a bright beam of light in a dark room. No wonder the English physicist Brown on observing the movement of pollen particles in water, at first thought that they were alive. To find out that this was not so, the scientist had to heat the pollen to a temperature at which life is impossible. He was surprised that on cooling, the movement of the particles continued. This random, disordered movement came to be called the Brownian movement, and it is caused by unbalanced impacts with molecules of the surrounding medium. The smaller the particles and the more they are commensurable in size with the surrounding molecules, the greater are the molecular forces that act on them, and consequently, the more vigorously they “fly” in the water. Exactly the same process occurs in a gaseous medium, i.e., in an aerosol.

Evidently the gaseous medium itself is not in a state of rest, especially if what we have in mind is not air in a closed room but the ejections of the metallurgical industry. The metallurgical gases in the plants and pipelines usually flow at a speed of 5 to 30 meters a second or 18 to 110 kilometers an hour. At such a speed, not only pollen, but even quite large particles are set in motion. Besides, the gas flow, in the main, is disordered and turbulent, varying its direction and velocity. Turbulence is enhanced with an increase in the speed of the gases, their density and the geometric dimensions of the flue. The particles, under the influence of the eddy flow, collide and begin to interact. The influence of molecular forces usually predominates when the particles are smaller than  $1\text{ }\mu\text{m}$  across; the influence of turbulence, when they are from 1 to 5 micrometers in size.

A third force that does not allow the dust particles to float indefinitely is gravity. No matter how small the dust particles are, nor how difficult it is for them to overcome the aerodynamic resistance of the gaseous medium, they settle down. Gravity is the force that influences the motion of the largest particles which are over  $5\text{ }\mu\text{m}$  in size.

At first glance it may seem that the field of action of each of these forces is strictly limited by the size of the particles. As a matter of fact, their spheres of influence overlap, and we observe an additive effect. Naturally this leads to still greater "chaos" in the movement of the particles, and consequently, more intense conglomeration and adhesion. It is also important that the dust particles are rarely of the same size, i. e., monodispersed dust. More often than not it is polydispersed, and that makes it possible for all three forces to act simultaneously.

When sampling, it is necessary to take into account the influence of all these forces, otherwise the data of the "reconnaissance", which is primarily interested in the quantity of the particles and their particle-size distribution, may prove to be unreliable. On counting the number of dust particles entering a flue (initially  $1\text{ }\mu\text{m}$  in size, moving at a rate of  $15\text{ m/s}$ ) and then recounting them only two seconds later, it was found that the number of particles decreased from 3 820 000 to 50. Usually the size of the conglomerates formed does not exceed  $5\text{-}10\text{ }\mu\text{m}$  because particles of this size almost never merge. The heavy particles "seek repose" and readily settle on the walls of the flue. Such particles may not get into the sample.

Try and take an "identifier" in such conditions. There is, nevertheless a way out of this "hopeless" situation, of which we will speak later on. First, let us suppose (although it is most unlikely) that the particles are free from the action of molecular forces, turbulence and gravity. In this case the particles entrained in a steady flow of gases surrounding them would move separately to the outlet of the flue. Excellent conditions for sampling, aren't they? It may seem that without the risk of error, a dust sample needed for analysis could be obtained by introducing a sampling tube into the flue and connecting it to a suction pump. However, even under such favorable conditions there is a chance of error because inertia of the dust particles is disregarded. Inertia, as we know, increases with the mass of the body.

Let us carry out the following experiment. We will introduce into a stream of air an equal number of small and large particles and then take samples at various velocities. Now competition will set in to see who is more agile, i. e., which particles will predominate in the sample. The larger particles which are more inert are slow-moving; they strive to maintain the initial velocity imparted to them by the gaseous flow. The small particles are "obedient" and readily acquire the velocity of sampling. Hence, if the sampling velocity is greater than that of the gas flow, small particles will predominate in the sample; and if it is less, large particles will predominate, and only if the velocities are equal, the number of particles and their particle-size distribution will be accurately represented in the sample. This is the first condition that has to be observed in sampling; it eliminates the influence of inertia of the particles.

It is impossible to eliminate the effect of the other forces that set the dust particles in motion. They can only be somewhat reduced by observing two other conditions. The intake tube is introduced in a straight section of the flue, where the gas moves as steadily and calmly as possible, and it is placed so that the cross section of the inlet is strictly perpendicular to the direction of the flow. This neutralizes turbulence, while Brownian movement and gravity do not have time to "confuse" the sample, because sampling is accomplished in a very short time. This is how samples are taken to find out what the "prime-vial" dust ejected from the metallurgical plant is like. To analyze the

collected dust, samples are taken either from the flue or the bin of the dust-collecting apparatus. This is not very difficult to do. After that “trial by ordeal” begins.

### **A Pound of Down or a Pound of Iron?**

The dust-collecting service, as has already been mentioned, is interested in two things: the particle-size distribution of the dust, i.e., its granulometric composition, and the mass of dust in a unit volume (cubic meter or liter) of gas or air, i.e., its mass concentration. It is difficult to say which of the two is more important. Both are important for choosing the type of dust collector, while the second is also important for determining its efficiency. In the second case samples are taken both before the gases enter the apparatus and after they leave it.

Different data imply different methods for obtaining them. Let us begin with particle-size analysis. It is not easy to separate fractions of the sample because the properties of the particles persist even after they are “captured”. The main difficulty, however, is connected with the shape of the particles. They can be spherical, plate-like, star-shaped, thread-like; their surface can be smooth or rough. Is it possible in these circumstances to compare their sizes and classify them? For instance, how can we determine which particle is larger – a sphere of a diameter of 5  $\mu\text{m}$  or an elongated plate of this width? To put such a question is in itself a mistake. The plate also has length and thickness. And what if it is not a plate but a star? What then? It is necessary, therefore, to make some allowances which do exist in all the measurement methods employed. That explains why they are conditional to some extent and why the results obtained by different methods often disagree. Practically, however, such a discrepancy is admissible.

There is a “test in jest”: “What is heavier a pound of down or a pound of iron?” Many unhesitatingly answer: “A pound of iron”. However, it is possible to understand those who fail in this test. They proceed from the fact that the density of iron is greater than that

of down and they erroneously take a pound to be a measure of volume.

But let us put another question: "What is heavier a sheet of paper or a ball compressed from this piece of paper?". If the sheet is placed on one pan of the scales and the ball on the other one, they will balance each other.

But there is some sense in this question. Let us drop the sheet and ball at the same time from the same height. Long after the ball reaches the ground the unfolded sheet will still "soar" in the air. Now let us reduce our model to microscopic dimensions. The situation remains practically the same. Spherical microparticles will land quicker than those of different shapes. The reason for this difference in behavior is the resistance of the air which prevents the particles from descending freely. As the particles fall their velocity increases, but so does the retarding force of the medium. As a result they finally descend to the ground at a definite velocity. This is called the floating velocity. It depends on the viscosity of the medium, the density of the substance, the shape of the particles, but most of all on their dimensions, thus making it possible to classify them according to size.



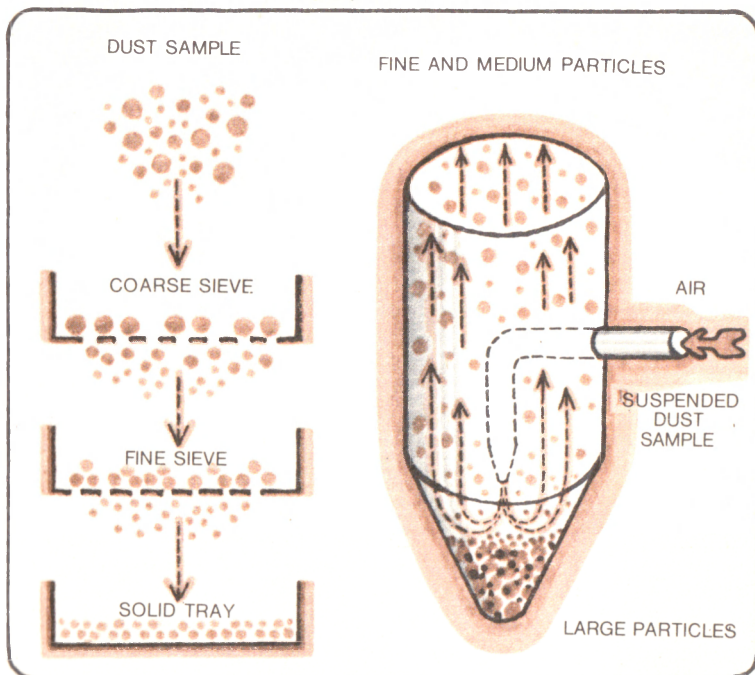
It has been assumed that particles of one size are those having the same floating speed. This dimension is taken as the diameter of a spherical particle with the same rate of descent and density as any particle of the given material, irrespective of its shape. The principle of grading particles according to their rate of descent is the basis of three methods of particle-size analysis: air separation in vertical cylinders, sedimentometry, and centrifugal separation.

The air separator works as follows. A dust sample is introduced into a stream of air moving at a constant rate into a cylinder (see the figure). Particles whose rate of descent is less than the velocity of the air are carried out of the separator, the rest settle down inside the separator. Successively using cylinders of three or four different diameters and changing the volume of the air fed into them, it is possible to isolate fractions of the particles that differ in their rate of descent. Each fraction is weighed and its percentage of the total mass of dust is then calculated.

Sedimentometry differs from air separation in that a liquid medium is used instead of air. The larger the particles, the sooner they settle.

In centrifugal separation, instead of using the force of gravity to isolate the fractions of dust particles, use is made of the centrifugal force which is hundreds of times greater, and consequently, the duration of the analysis is considerably reduced.

Air separation in vertical cylinders began to be used in the 1920s, sedimentometry in the 1950s, centrifugal separation is even more recent, and the oldest method of particle-size analysis is sieving. It is very simple. The dust is sifted like flour, the sieve (hand-operated or power-operated) moving with a see-saw motion. The apparatus used for power-operated sieving consists of a set of several sieves with different meshes. The dust particles, depending on their size, are retained on one or another sieve; the finest particles pass into the solid tray. It is now only necessary to weigh each sieve and the tray (together with the dust retained on them) and to subtract from

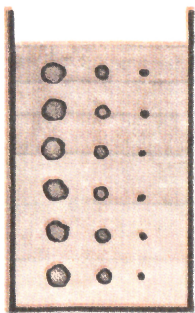


Sieve analysis (on the left) and air separation (on the right)

each weight that of the empty receptacle. The respective fractions are then easily calculated.

All the above methods give an idea of the mass of the dust in a given fraction. But which method should be chosen? In each concrete case all the pros and cons must be considered.

Sieving is not a long procedure; it takes about 20 minutes. But its utility is limited. It cannot be used for particles smaller than  $40\text{ }\mu\text{m}$  across because there are practically no sieves with finer meshes. That is why sieving is used as a preliminary analysis in conjunction with finer methods. Sieving is only used as an



Sedimentometry:  
prior to  
sedimentation  
(above) and the  
settling pattern  
after a time  
(below)

independent method for analysis of the dust collected in processes where coarse dust is formed, for example, during grinding of drying furnace charges.

Air separation and sedimentometry are labour-consuming procedures. It takes several hours to obtain test results. Much time is also needed to change the operating conditions of the air separator when each successive fraction is isolated. But the range of these methods is different—they work with particles smaller than  $40\mu\text{m}$ . Consequently, the applicability of these methods and that of sieving do not intersect. As concerns air separation and sedimentometry, these methods are used to the same extent, except when the dust particles are inclined to dissolve or conglomerate in a liquid, making sedimentometry unfeasible.

Centrifugal separation is the most progressive method: the analysis takes about two hours, and in the fraction with the smallest particles their size ranges from four to eight micrometers. Nevertheless, centrifugal separation is not widely used because it requires special apparatus.

It may seem that everything is clear and simple enough. But it is far from being so. The size of the smallest particles can be considerably less than four micrometers; this is characteristic of sublimated dust (sublimates) which is very



valuable and important in technology. In contrast to mechanical dust that is evolved in grinding, transporting or raising the temperature of the furnace charges, fumes are formed from the vapors of molten metals and their compounds.

On entering a medium with a lower temperature, the metal vapors condense and form tiny liquid drops, which immediately solidify and are converted to dust particles. These particles can be 1-2  $\mu\text{m}$  in size and in some cases even smaller. If the particles are smaller than one micrometer they can be discerned only under an optical or an electronic microscope.

Although neither of the microscopes can be used to isolate fractions for weighing them, microscopy is used for particle-size analysis. Only in this case it is not the mass of the fraction, but the number of particles in it that is determined. The percentage of each fraction is found from the ratio of the number of particles in the fraction to the total number of particles. Counting the number of particles is very labour-consuming, and it is now carried out by special automatic devices designed for this purpose.

The final result of any particle-size analysis is the plotting of a graph of particle-size distribution, which shows what size predominates and consequently what dust-collecting equipment is required. If small particles predominate, an apparatus of complex design is needed; if large particles predominate, a simpler one is adequate.

## **The Triple Alliance**

The dust-collecting service in metallurgy did not originate by chance. It was necessitated by the vital needs of man. It was essential to provide safe labour conditions, and normal conditions for maintaining life and, finally, to preserve the raw materials emitted with the gases from metallurgical plants. Three big problems merged into one common cause: labour protection, environmental protection and the rational utilization of natural resources. The responsibility for solving these problems was shared

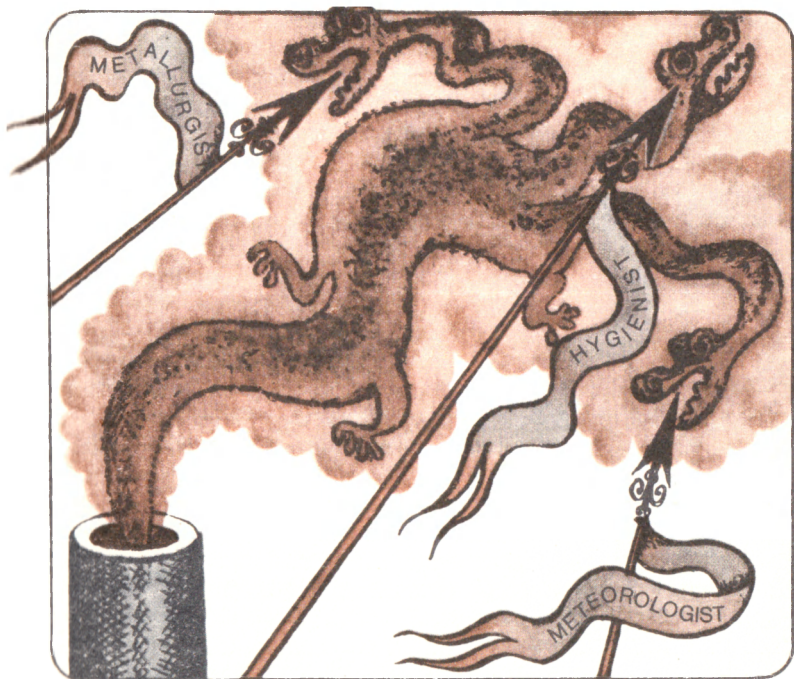
by metallurgists, medical workers and meteorologists, whose duty it became to monitor the purity of the air at plants and beyond their premises. The sanitary services and weather bureaus began to send out "scouts" whose purpose, to some degree, coincides with that of the dust-collecting service. It is also imperative for hygienists to know, in particular, the dust content in gases and in the air, i.e., the dust concentration. The point is how the data are obtained and by whom, when, and for what purpose they are used.

There is a popular song in this country with the following words: "Oh the roads, the mists and the dust...". Everyone knows that neither mist nor dust promises anything very pleasant. But does anyone bother to think about the physical essence of these natural phenomena? Hardly. Dust and mists are aerosols as we already know. The difference consists in that for dust the dispersed phase is composed of solid particles, while for mist of liquid ones.

In dust-collecting practice, aerosols are classified not only according to the nature of the dispersed phase, but also according to the size of the particles in it. Aerosols with a solid dispersed phase are subdivided into three types: coarse dust (over 10  $\mu\text{m}$ ), fine dust (from 10 to 1  $\mu\text{m}$ ) and smoke, in other words, fumes (less than 1  $\mu\text{m}$ ). Aerosols with a liquid dispersed phase are subdivided into spray (drops 10-1  $\mu\text{m}$ ) and mist (less than 1  $\mu\text{m}$ ). Obviously, the greater the number of these particles in the air, the worse for man.

You have surely often heard the warning in weather forecasts: "We expect mist in the morning. Poor visibility". Then the mist is lifted and the outlines of objects become clear and sharply distinct, just like transfers freed from tissue paper. Visibility is better. The light rays from the objects, previously shut off by the mist, have now reached your eyes unimpeded.

The fact is that the very small drops that make up the mist reduce the intensity of light in proportion to their number. Solid particles of dust produce the same effect. It is namely this effect of airborne dust that some modern devices use to determine its content in gases and in the air. The chief advantage of such devices



over time-tested devices based on gravimetry is the speed with which the analysis is performed.

In the gravimetric methods samples of gas or air are taken, filtered and then the filter together with the dust retained on it is weighed. The mass of the dust is found by subtracting the weight of the filter. The volume of the gas passed through the filter is measured and recorded by a special device. By dividing the mass of the dust by the volume of the sample we obtain a value that characterizes the dust content in the gas or air in grams or milligrams per cubic meter.

At first glance, the gravimetric method is not so complex. But this is only at the first glance. The laboratory workers have to take great pains when carrying out the analysis. Many attempts have been made to automate the method, in particular, the process of weighing the deposited dust. But this proved to be extremely difficult. Just the same the problem has to be solved because the demand for such tests has grown considerably as well as the need for speeding them up.

What has already been achieved in this respect? Indirect methods for determining the dust concentration have been found, which rely on the reduction of light intensity caused by the presence of dust in the gases. Some devices use ordinary light rays; others, beta rays; in still others, a laser beam. But in all three cases the greater the concentration of the dust, the more it reduces the intensity of rays, whatever its nature might be. The intensity is graduated in units of dust content (grams or milligrams per cubic meter). The test result is ready almost instantaneously.

The gravimetric method and the indirect methods based on the reduction of beam intensity are used by sanitary inspectors and those engaged in dust collecting. They are intended for gas control.

The dust content in the air of shops and on the plant premises is measured with a konimeter—a meter that counts the dust particles. It is also used by meteorologists and the sanitary service. It conforms to the present requirements of operative analysis. The principal parts of the apparatus are a pneumatic pump, a glass disk and a microscope. The pump sucks a definite portion of dust-laden air into the apparatus. The dust particles on impact with the glass disk are deposited on it and are counted under the microscope. The apparatus is equipped with a projector which projects the image on a paper screen to facilitate counting. On it the counted particles can be marked so as not to lose count. The apparatus is also used for particle-size analysis as it has micrometer divisions to quickly determine the size of the dust particles so as to take each fraction into account separately.

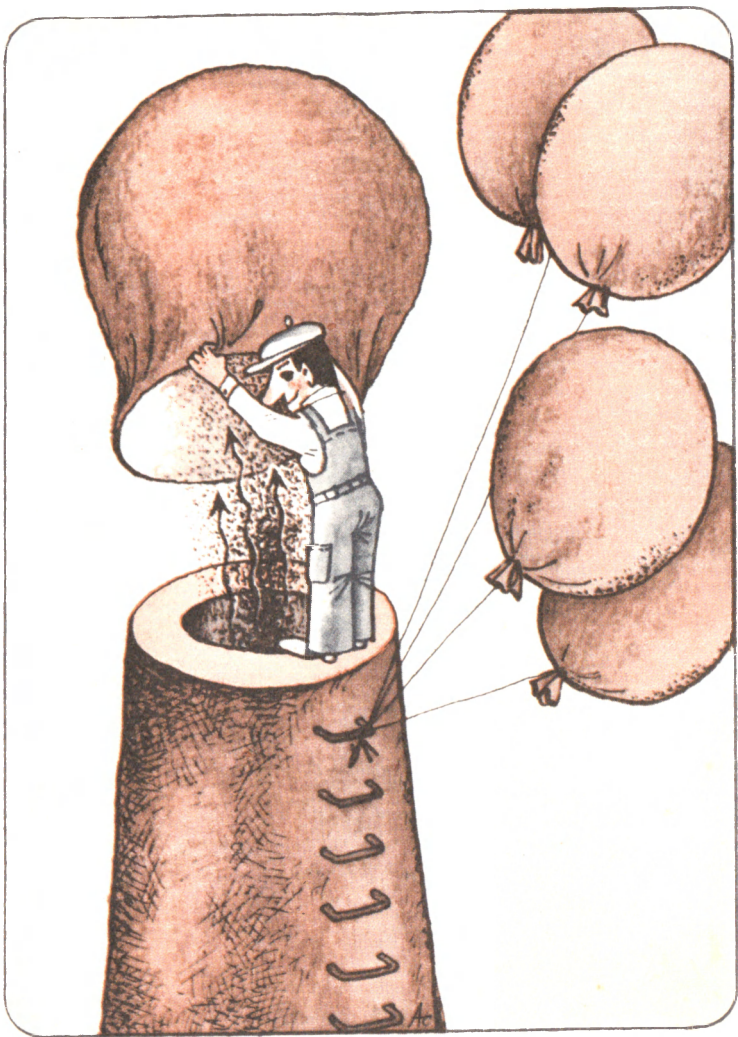
This is how the dust concentration is measured. But what is this done for? In the dust-collecting service, data on the concentration

of dust and its particle-size composition is the starting point for choosing appropriate dust collectors. This data is also needed for checking their efficiency and regulating their operation. We have already spoken about this.

Sanitary inspectors are primarily engaged in monitoring the air at the working places. They are interested in unorganized emissions, i.e., those which do not leave the metallurgical plant with the gas flow but leak into the shop premises due to lack of air-tightness of the furnaces and during teeming of the metal or feeding of the furnace charge, flux or other material. Unfortunately, these emissions still constitute a considerable part of the total gas emission. Hygienists keep watch that the dust concentration in the air in the shop and in the vicinity of the works does not exceed the permissible concentration (of that we will speak separately). The operation of the dust collectors is also under the surveillance of the sanitary service.

And, finally, how about the meteorologists and weather bureaus? Their activity is evident from the fact that today over 450 large industrial centres in this country are constantly monitored by them and the plants receive their instructions to curb emissions if atmospheric conditions demand it.

In this way, the triple alliance: metallurgists, medical workers and meteorologists use the data on the dust concentration in the gases and in the air.



## **DUST-COLLECTING SERVICE**

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### **Prior to Choosing**

For a long time the only means of fighting dust and other pollutants was the smoke stack through which the dust-laden and contaminated gases were withdrawn at a great height and dispersed in the atmosphere. This helped reduce the concentration of harmful gases and dust near the ground. At the present time the stack can only conditionally be called a cleaning device, only when referring to times long gone by. Nevertheless, in this way our ancestors protected themselves to a certain extent from the harmful effect of emitted gases and dust. During the time that smoke stacks have served man, they have been improved and become taller. In Belgium, for example, a stack was built that rose 380 meters into the sky—a skyscraper 125 stories high! However, even a stack that rose above the clouds (there is also such a project) cannot save the ocean of air from pollution; it can only reduce the concentration of harmful emissions near the ground. That is why the stack as a cleaning device has been replaced by special dust-collecting facilities. There are more than enough of them now. Only in this country, the dust-collecting service has at its disposal up to a hundred different “traps” and “snares” for dust particles: various cyclones and dust chambers; all kinds of filters—cloth, fiber, granular filters, etc.; electrostatic precipitators; wet dust collectors—scrubbers, Venturi tubes and others.

What a big choice! Perhaps it is too big? Well, probably not, considering the specific character of the metallurgical industry which yields tens of different metals. Each is produced by its own technology. The metallurgical plants are also different. Hence, the diverse chemical composition, shape, size and number of dust particles. And as you already know, these are the main characteristics for choosing the appropriate dust-collecting apparatus.

But these are not the only factors that determine what apparatus

is chosen. The dust particles are conveyed from the metallurgical plants by a stream of gases. Therefore, it is necessary to take into consideration the chemical composition of the gas, its temperature and humidity (i.e., the content of water vapor in it).

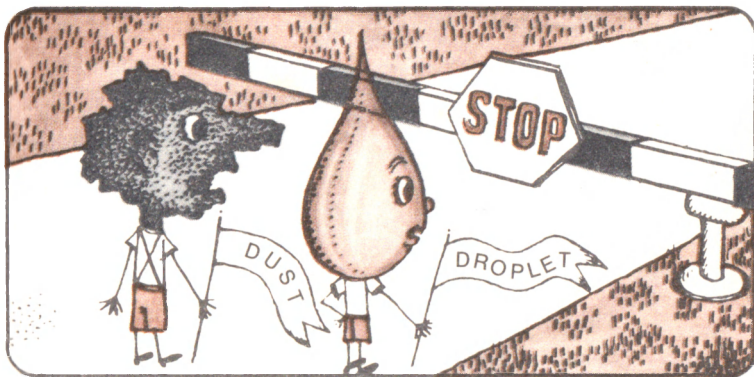
The gases can contain substances which unite with water vapor to form alkalies and acids. This results in corrosion. The temperature of the gases can be as high as several hundred and even one thousand and more degrees, and only specially treated dust collectors can withstand such heat. Besides, the higher the temperature of the gases the more "stubborn" they become and the greater the force that must be applied to convey them through the flue or draw them through the dust-collecting apparatus. With a rise in the temperature there is an increase in the viscosity of the gas, that is, the friction which one layer of gas overcomes when moving in relation to another one rises. And it is just of such movement that the general motion of the gas stream is composed.

But can the data on the nature of the aerosol, i.e., of the dust and gas, be considered to be exhaustive for choosing a dust collector? Certainly not. Data on the dust-collecting apparatus is also necessary. Just what data?

Recall how tiring it is to drive a car on a dirt road, how long the way seems even if it is actually short, and how glad you are to leave it and drive on a paved road. The road no longer puts obstacles in your way and you can speed along, conforming, of course, to the driving regulations. "A good road at last," you sigh with relief. But what does "good" mean? Do our words only express a feeling of physical comfort or can they be interpreted from the physical point of view? Yes, they can. It is known to all, but it does not occur to everyone at the moment that the car could now increase its speed because resistance to its motion was reduced.

Water and gas are not solids but they also meet resistance when they come in contact with solid bodies. So the pipelines through which liquids and gases are conveyed resist their motion. This resistance is called hydraulic, from the Greek "hydor"—water. It can be either uniform, i.e., constant throughout the whole way, or local, due to widening or narrowing of the stream or when it meets





some obstacle. The motion of gases and liquids is governed by the same laws, therefore the term “hydraulic resistance” applies in both cases.

Thus, hydraulic resistance is one of the most important characteristics of dust collectors, and it must be taken into account to secure adequate dust collection and the required rate of gas removal from the plant. That is why ventilators are constant “co-travellers” and “assistants” of dust collectors. Their capacity is directly related to the hydraulic resistance, determining the energy consumption and economical operation of the apparatus.

Another characteristic that is just as important is efficiency, that is, the proportion of the entire mass of the particles (in per cent) which is caught in the “net” of the dust collector. For example, if 90 grams out of every 100 grams of dust in the gases is retained in the device (in a given period of time) then its efficiency is 90%. The efficiency of different apparatus varies from 50 to 99%. Besides general efficiency, there is also fractional efficiency, i.e., the proportion of the retained particles of one size. The efficiency of an apparatus indicates its feasibility, showing what it is capable of and whether it is expedient to use it at a given dust concentration and

particle-size composition. Here is where the data of the "scouts" of the dust-collecting service becomes useful.

Besides the hydraulic resistance and efficiency, it is necessary to know the highest operating temperature, dimensions, mass, and power consumption of the dust collector.

The working temperature usually does not exceed 500°C. In some kinds of smelting furnaces, however, the gases are emitted at a temperature twice or three times as high. Fighting such gases may cost the dust collector its life. To avoid this the gases are cooled in waste-heat boilers, then mixed with cold air and water injected into the gas flow.

As to the dimensions and mass of the dust collector, their significance is obvious. It should only be pointed out that the size of the apparatus plays a dual role. On the one hand, the greater the capacity and efficiency demanded of them, the larger they are, as a rule. On the other hand, the choice of an apparatus of a given size is limited by the actual conditions at the works. It is necessary, for instance, to decide whether there is enough space on its territory to mount a tower 5-6 m in diameter and 15-20 m tall (these are the approximate dimensions of some efficient dust collectors). It is rather difficult to solve this problem for works with a considerable service life because it is just there (in case of reconstruction or replacement of worn-out dust-cleaning equipment) that more effective and, most frequently, large apparatus are required.

The mass of the dust collectors, naturally, depends on their dimensions which must be taken into account in order to determine the required extent of building and assembly work, the consumption of metal and the cost.

The last characteristic of a dust collector is its capacity. It varies from several thousands to hundreds of thousands and even millions of cubic meters an hour. The choice of an apparatus according to its capacity depends on the concentration of the dust and the volume of the gases being cleaned.

Thus, the selection of a dust collector is a problem with many variables. Is it easy to take all of them into account? Couldn't computers be of help to the dust-collecting service? In principle

they could be, but there is no special need for them. The point is that the "snares" and "traps" for dust are subdivided into several large groups depending on their mode of operation. Each group has its characteristic features. The "ability" of the apparatus of each group is determined by the forces that drive the dust particles out of the gas flow, whether it be the force of gravity, diffusion, inertia, an electric field, etc.

Therefore, prior to choosing a dust collector let us familiarize ourselves with the working principle of each group.

### **In a New Capacity**

What we are going to talk about now, though paradoxical, is in fact true. When speaking about means of collecting dust, it is dust-collecting (settling) chambers that are first called to mind. It is always pointed out, however, that they are used with reluctance and that they are out of date and from the beginning of the century have begun to disappear from industrial sites. In the meantime the end of the century is approaching and dust chambers still give useful service. What is the secret?

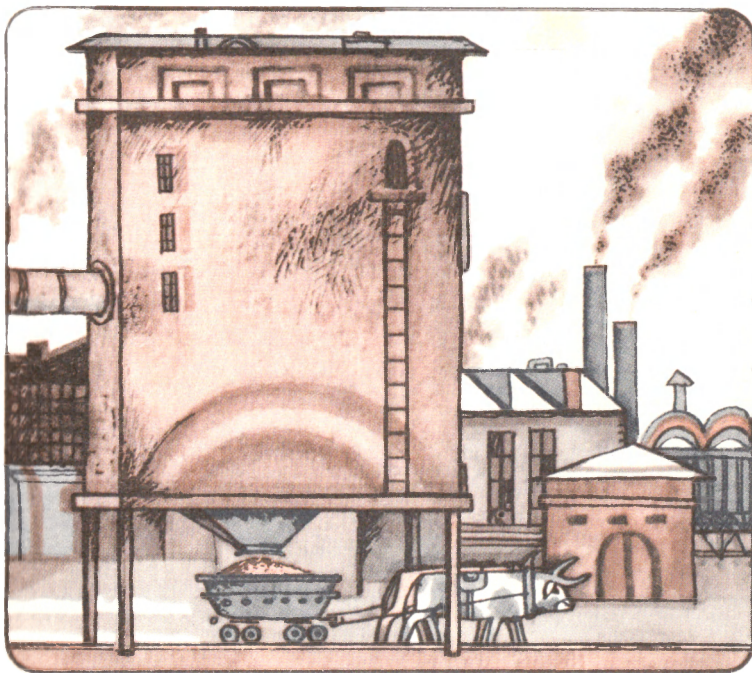
First of all, what is a dust settling chamber like? A most simple construction. A two-storey house made of concrete (sometimes of steel) without interim floors or ceilings. The house has "doors"—an entrance and exit. Through one of them the dust-laden stream of gas enters and through the other one it emerges already partly freed from dust (there are also "windows"—manholes with lids for inspecting and cleaning the chamber). The dust particles are precipitated on the bottom of the chamber and are collected in bins from which they are discharged in wagons which move under the chamber. These unsophisticated installments for collecting dust are very reliable and do not consume much energy because their hydraulic resistance is small—5-10 mm of water column, i.e., 50-100 pascals. That is equal to the pressure exerted by 50 grams of sand on a palm. The gas practically passes freely through the chamber, and nothing hinders the horizontal motion of the dust particles either; nevertheless, they fall onto the floor, driven by the force of

gravity. The same force that draws all bodies on and near the Earth towards its center.

We have already spoken of the effect of this force on dust particles when describing sampling. Only then it was necessary to neutralize gravity in order not to reduce the accuracy of the analysis. When collecting dust, on the contrary, gravity is used to remove the dust particles from the gaseous medium. Is that easy to accomplish? Yes, it is not difficult. However, in order for gravity to “work”, certain conditions are required. What are they? To calculate, with sufficient accuracy, the dimensions of the chamber—its length, width and height.

The fall of a dust particle resembles the descent of a parachute. To land precisely it is necessary to take into account the strength of the wind and to estimate at what height the parachute should be opened. In a dust chamber the wind is the gas flow and the place of landing of a dust particle is limited by the area of the bottom of the chamber. The size of this area is important also because each of its dimensions—the length and the width—determines the time a dust particle spends in the chamber. The length, because the longer the chamber, the greater the chance for the particle to land; the width, because together with the height it gives the cross section of the chamber which in its turn determines the velocity of the gas flow. The larger the cross section, the slower the gas flows, like a river passing from a narrow ravine to a very wide valley. Still the length and the width of the chamber cannot be infinite.

Of course it is desirable to completely free the gas of dust. Is it possible to do this in dust chambers? Let us try to answer the following question: how much time, for example, would it take a  $2\text{ }\mu\text{m}$  particle of metallurgical dust (it can be even smaller) to reach the bottom of the dust chamber? The conditions are: the height at which the particle enters the chamber is 1 meter; the floating speed of the particle, 0.001 meter per second. It should be recalled that the floating velocity depends on the density of the substance and the viscosity of the medium determined by temperature. Simple calculation shows that the dust particle will reach the floor in 1 000 seconds. But in that time the gas flow



would carry it 1-2 kilometers away if it is assumed that, as a rule, the gas moves in the chamber at a rate of 1-2 m/s. It turns out that fine dust practically cannot be precipitated by gravity. This applies not only to dust 1-2  $\mu\text{m}$  and less in size, but to larger particles up to 50  $\mu\text{m}$ .

When designing a chamber, account is taken of the sizes of those dust particles 90 per cent of which must be collected, the amount of gas ejected from the plant and the preset height of the chamber. In order that the chamber be as compact as possible, it is expedient that its height and width be the same; and to decrease the length, transverse shelves are installed, spaced 20 cm apart. Then even

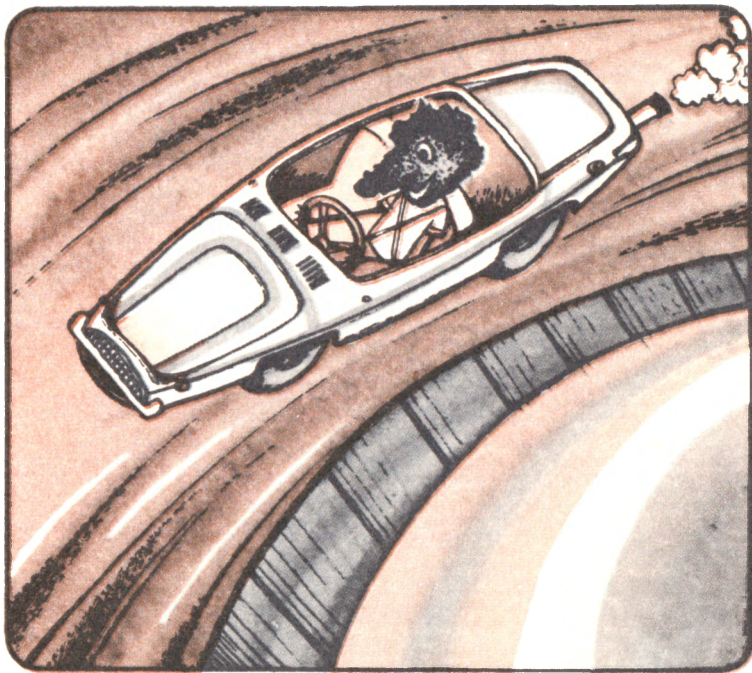
particles at the top of the gas flow will be caught in the “net”. But this applies only to large particles. The efficiency of collecting polydispersed dust amounts to 30-40%. Despite all the skill of designers, the size of the chamber is very large and is usually tens of meters long. That is their great disadvantage. Another disadvantage is that they are not airtight if they have no metal housing. When shelves are installed, an additional disadvantage is the difficulty of freeing them from precipitated dust.

So what predominates, the disadvantages or the advantages of dust-collecting chambers? There are plenty of both. Therefore chambers are used according to their “ability” for collecting large particles and for cooling the gases. In other words, dust chambers are the initial stage in the process of dust-collecting. Together with them in one team are successively connected other dust collectors, such as cloth filters, cyclones, electrostatic precipitators capable of finer work. Only then effective gas cleaning is attained. Hence, it is still too soon to discard dust chambers. Their functions are different, but in their new capacity their use in some cases is fully justified.

## **The Way to Perfection**

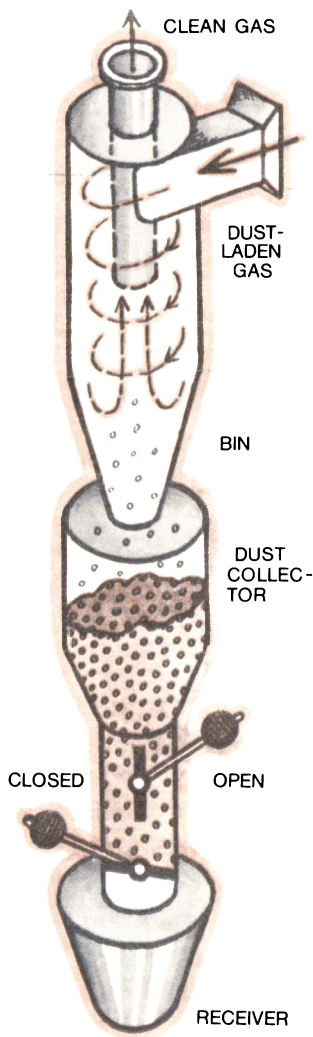
Centrifugal force... Magicians, rotating a vessel filled with a liquid, astonish the audience when the liquid does not pour out of the vessel on turning it upside down. Motor racers rushing up a vertical wall are accompanied by rapturous cries and applause. Athletes hurdling a hammer for distance of tens of meters, accelerate its speed by turning their own bodies. And what about technology? Without the fear of being mistaken it can be said that there is no field of technology that fails to make use of this force, and man has long ago come to understand its advantages over gravity: the centrifugal force can impart to bodies an acceleration that is tens, hundreds and even thousands of times that of free fall. From 2 to 2500 times greater. Powerful, isn't it?

Ever since dust collecting entered the phase of intensive development it has also turned to the aid of centrifugal force. The



designing of dust collectors based on the use of this force dates from the beginning of this century. These dust collectors are called cyclones from the Greek word which means circle. The gas flow in them moves in a circle, or a spiral, to be more exact, and the dust particles, striving to retain a rectilinear motion, are precipitated on the walls of the apparatus. If liberated they would fly like sparks from a whetstone. While dust chambers precipitate approximately 90% of the particles larger than  $50\text{ }\mu\text{m}$ , cyclones settle down the same percentage of finer particles ( $5\text{-}25\text{ }\mu\text{m}$  in size).

How is this rather simple and very effective apparatus for collecting dust designed? Its metal housing consists of two parts: the upper one is a cylinder and the lower one is a cone. The



cylinder contains an inner cylindrical exhaust pipe of a smaller diameter for the cleaned gases. The main purpose of the apparatus, to impart a rotary motion to the gas flow, is accomplished with the aid of a connecting pipe, usually a rectangular one, which is placed tangentially to the cylindrical body.

Under the cone there is a hopper for the precipitated dust. In principle, that was what the first cyclone was like. Not much has changed in it since then except that its design and operating conditions have been improved. The years (tens of them) during which this apparatus has been used were years of search for means of perfecting it. The chief purpose of research was to raise the efficiency and capacity of the cyclones. All this time, experiment and practice went side by side with theory because it proved to be impossible to calculate the optimum design only theoretically. The aerodynamics of collecting dust in cyclones is very complex, and when deriving the formulas characterizing the process, it was necessary to make many assumptions. Nevertheless, the engineers were able, with sufficient accuracy, to determine the effect of many important factors on the work of cyclones.

Cyclone with an air-locked dust bin



What are the laws governing the collection of dust in cyclones? First of all, the designers noted the significance of the velocity of the gas flow on entering the apparatus. The greater the velocity, the greater the centrifugal force and, consequently, the better the dust is "caught". The collection of dust particles is speeded up with an increase in their mass, i.e., their size and density; and the dimensions of the apparatus play a big part: the precipitation of a particle is the quicker, the shorter its path from the exhaust pipe to the walls of the cyclone; in other words, the smaller the difference in the radii of the two cylinders.

The following conclusions inevitably rise in the mind. To increase the efficiency of the cyclones it is necessary to increase both the velocity of the gases on entering the apparatus and the mass of the dust particles, and to reduce to a minimum the difference between the radius of the housing and that of the exhaust pipe. Unfortunately, however, in all these conclusions made on the basis of theoretical premises there are many "buts".

Let us begin with the increase in the velocity of the gases entering the cyclone. It is not difficult to attain this: it is enough to install a more powerful ventilator upstream or downstream of the apparatus and the gases will gain an adequate acceleration. But ... if the velocity exceeds a certain limit, eddy currents will tear away the precipitated dust and it will not get into the bin but into the exhaust pipe. Experiment and practice defined the most effective velocity for collecting dust to be 20-25 m/s, i.e., 70-90 km/h.

Next, about particle size and density. Here is another "but". It is practically impossible to increase them. Conglomeration can increase the particle size, but the density will accordingly be reduced. The cyclone can be used effectively only for particles over 5  $\mu\text{m}$  in size. This is much better than the dust chamber is capable of; still it cannot "catch" fumes either.

Finally, the correlation between the radius of the housing and that of the exhaust pipe. Here there are two more "buts". First, if the difference is too small the inlet can become clogged with dust, especially if the dust tends to stick together or its concentration is great. Secondly, precipitation of dust becomes worse with an

increase in the diameters of the outer and inner cylinders even if the difference between them remains the same. Therefore, to secure efficient dust collection it is recommended that the diameter of cyclones does not exceed one meter.

It is hardly necessary to explain why despite their high efficiency, cyclones of this size cannot satisfy the growing needs of metallurgy with its abundance of dust and gases. Their capacity is insufficient not only for metallurgy but also for other industries where gases must be freed from dust. That is why a new design had to be found. Cyclones began to be installed in groups with one collecting bin in common. An indispensable working condition for such a group is that all the apparatus be of one type, manufactured to the same geometry, and have the same hydraulic resistance so as to share the gas load equally.

By the way, when designing cyclones, the hydraulic resistance must be taken into account. It is found by testing the apparatus in a test set or in industrial conditions, and the so-called hydraulic factor is determined. It depends on the design of the apparatus and, in some cyclone designs, also on the body diameter and the dust content in the gases. Additional corrections are introduced to account for these factors. That is how experimental data are used to introduce corrections into the formulas.

Let us now return to grouped cyclones. Although their total capacity is greater than that of each individual cyclone, it is also limited: not more than eight cyclones in rectangular arrangement and fourteen in circular grouping are recommended. The construction obtained is unwieldy. That's where the idea of multi-unit cyclones (multiclones) originated. Up to 160 units can be arranged in one multi-cyclone. The diameter of the housing of each small unit cyclone varies from 40 to 250 mm. It is impossible in such small devices to set the gas flow spiraling with the aid of a tangential nozzle because a separate gas-admission nozzle for each unit would greatly increase the total size of the multiclone. It has been decided to use oblique blades arranged at the inlet into a screw or a rosette to spiral the gas. Units with screws proved to be less effective than those with rosettes, but more reliable, as they

are less liable to be clogged up with dust. As in the case of grouped cyclones, the units must be of the same type and have the same hydraulic resistance.

What other trends are there in the improvement of cyclones? One of them, of no small significance, is the selection of the proper material for the housing of the apparatus. It proved to be expedient to weld cyclones from sheets of steel 4-8 mm thick, and to cast the multicclone units from cast iron or, as in single cyclones, weld them from steel. If the temperature of the gases is about 100-200°C, thermal insulation of the outer surface of the cyclone is provided. When cleaning gases with a temperature above 400°C, the internal surface of the housing is coated with a refractory material, lined with bricks or tiles and the exhaust pipe is made of heat-resisting steel or ceramics. If the dust is highly abrasive the walls of the cyclones are protected by basalt tiles or some other abrasion-resistant material.

Another trend is to guarantee airtightness, especially for the devices discharging the precipitated dust. If in this operation atmospheric air gets into the cyclone, the dust will return to the gas from which it precipitated. If the quantity of the air drawn in amounted to 10-15% of the gases being cleaned the effectiveness of the dust collection would fall to zero.

How airtightness of the bins for collecting dust is achieved is of interest. While the bin is closed, naturally, no air is drawn in. That happens when the bin is discharged. Open the window and fresh air will come in from the street. That is why devices were invented that made it possible to discharge the dust and retain airtightness. One of them is a double gate valve. It consists of two flaps at some distance from each other that open alternately. Because of that the dust does not immediately go out of the bin, but enters a lock between two doors. When the first flap closes, the second one opens. The dust is already outside of the apparatus. The layer of dust itself creates an additional seal; its importance is the greater, the higher the pressure (or vacuum) under which the apparatus works.

Attempts have been made and are being made to change the

configuration of one or another detail of the cyclone, for example, the inclination of the inlet nozzle to the horizontal or the angle of the apparatus bottom cone. This does have some effect but, in principle, does not broaden the limits of cyclone application.

It should also be pointed out that in comparison with the time when cyclones were first used, they are now more efficiently operated. As a result centrifugal apparatus occupy a firm position among other dust-collecting apparatus. They are widely used not only in metallurgy but in the cement, coal, and chemical industry and also for dust removal from the gases ejected from boilers and heating plants. Cyclones are constantly being perfected.

### **Cleansing Shower**

The rain, like a gigantic shower, comes pouring on the ground, beating on the roofs, rustling the leaves, splashing the newly formed puddles. And following this life-giving torrent come the clean fresh air free from dust, and the coolness bringing relief. Is it not the discovery of this miracle of nature that put the idea into the head of the man who first thought of using water to clean gases from dust? In any case, to use the new terminology, he succeeded in simulating this natural phenomenon. The simplest wet dust collector—the jet (or spray) scrubber—can safely be called a “rain chamber” for dust-laden gases. The chamber usually has the shape of a cylinder with a conical bottom. The “rain” is created with the aid of jets or sprayers resembling in shape the nozzles of firehoses. The gas is passed through the chamber, the liquid is pumped into the sprayer; the drops coming into contact with the dust particles make them heavier and cause them to precipitate.

A great number of apparatus have been produced for wet dust collection; they differ in design and efficiency. However, as different as they may be, they serve the same purpose: to assure the best conditions for bringing the dust particles in contact with the liquid. According to the laws of physics there are several factors that can lead to precipitation of the dust particles on the drops. The first one is inertia with which we are already familiar. Not all of the

dust particles carried by the gas flow can avoid the obstacles in the form of drops. The larger particles retain their rectilinear motion and come in contact with the drops. Only the velocity of the gas flow must be great enough. The mechanism is the same as that described when speaking of sampling.

Then we also spoke about the Brownian movement. In the process of wet dust collection this is a second important factor that promotes the precipitation of dust on the drops. In contrast to inertia, it rises in importance at smaller velocities of the gas.

Other factors can operate as well, such as turbulent diffusion, electric forces (if the charges on the dust particles and the drop are opposite), polarization diffusion (if water vapour condenses on the dust particles or on the surface of cold drops). However, for wet collection of dust, precipitation due to inertia and from Brownian movement is most important.

What conclusion should be drawn? It is necessary to design apparatus in which these factors would be the most "active". This is namely the course taken in the development of wet dust collection, by which considerable success has been achieved. Suffice it to say that



some wet dust collectors are quite capable of competing in efficiency with cloth filters and electrostatic precipitators. It has even been widely disputed which should be preferred—dry or wet methods. Apparently, however, the wet methods will have to make way for the dry ones. But of that we will speak later.

Thus, we already know what the simplest wet apparatus, the jet (empty) scrubber, is like. It should be added that the scrubber efficiently collects particles larger than  $25\text{ }\mu\text{m}$  in size. Gases are passed through such an apparatus not only (rather not so much) for dedusting them but for saturating them with water (without which in many cases, subsequent cleaning is impossible) and also for cooling. This pertains to those jet scrubbers in which the diameter of the sprayer is 10 mm and more. Jet scrubbers with sprayers having outlet diameters of 1-2 mm are used exclusively for preparing and cooling the gases. The operation of such apparatus is more complicated because the sprayer easily becomes clogged up with dust, although theoretically they should be more efficient. Fine spraying of water creates a large surface for contacting it with the dust and thus increases the probability of contact.

The tendency to increase the contact surface between the dust and the liquid has led to the appearance of packed scrubbers. As packing material use is made of coke, quartz, ceramic rings (Raschig packing rings), wooden laths. As a result, the hydraulic resistance of the scrubber sharply rises and so does the consumption of energy. This is especially noticeable when the packing becomes clogged with dust. It is a difficult task to free the packing from dust. Hence, such scrubbers are frequently replaced by jet scrubbers with intensive spraying. The greater the number of drops of liquid, the greater the probability of their contact with the dust particles.

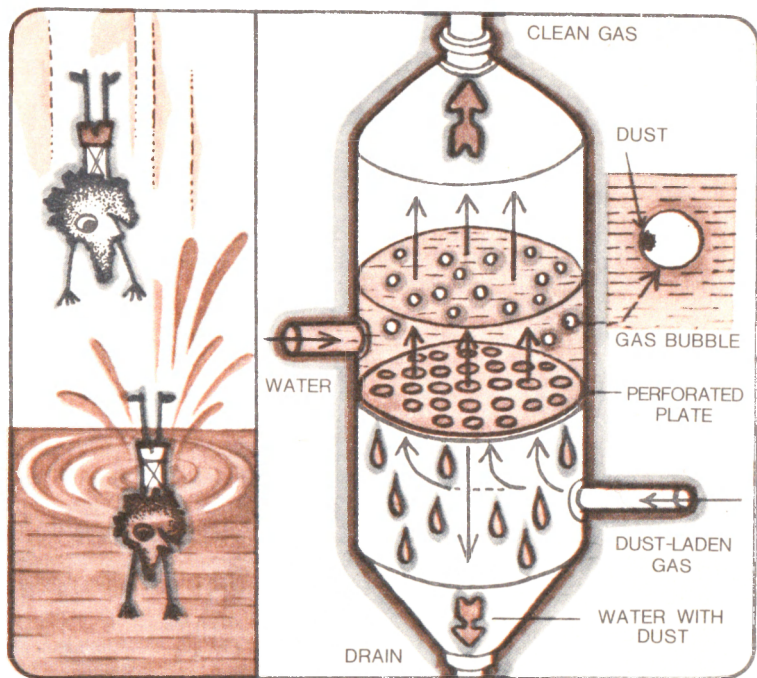
It should be pointed out that wet dust collectors share a peculiar feature: whatever their design may be, their efficiency depends to a considerable extent on the energy consumed. If it is the same, then the effect achieved is approximately the same. Energy is spent on overcoming hydraulic resistance, on supplying the liquid and spraying it finely. Taking into account the high cost of energy it is

not always expedient to increase its consumption. In high-speed wet dust collectors considerable energy consumption is justified, but in others it should be limited. It is precisely this that determines the size of the particles to be collected.

There is another variety of scrubber, the impact scrubber. "Rain" is a good thing but it is made up of separate streams and between them there can be a "dead zone" and, consequently, a part of the dust particles are not entrapped by the water. In this sense a continuous water surface is more reliable. The layer of water in an impact scrubber is at the bottom of the housing. The dust-laden gases enter at the top through a nozzle—there is a distance of several millimeters between the end of this nozzle and the water surface. The gas strikes the water surface with a hurricane-like gust, and shattered into drops the water leaps upward. And what about the dust particles? Their "fate" can vary. The larger ones plunge into the water and sink to the bottom; the smaller ones, which avoid this lot, are caught up in the spray formed on impact of the gas and the liquid. After that the same thing takes place as in an ordinary scrubber. Thanks to the twofold contact of the liquid and gas, it is possible to precipitate particles down to  $10\text{ }\mu\text{m}$  in size. Such results can be obtained neither in cyclones nor, of course, in dust chambers.

Can a layer of water be used as a filter, passing a stream of dust-laden gas through it? This idea was realized in practice in an apparatus called a bubbler. The liquid layer in it is 50-100 mm thick. The gases enter at the bottom and getting into this layer break up into bubbles 3-7 mm in diameter—small air bubbles in each of which there are dust particles. The air bubbles rise to the surface, like air exhaled from an aqualung. They join the gas flow again, but on the way they lose the dust particles which approach the shell of the bubble and pass into the liquid. This can result in one thing only—they sink to the bottom. Only particles less than  $5\text{ }\mu\text{m}$  in size succeed in passing through the water screen.

High-speed dust collectors (HDC) are not yet 30 years old. They made their appearance in the 50s and immediately came to occupy one of the leading positions among dust-collecting equipment. No



Operation principle of an impact scrubber (on the left) and bubbler (on the right)

wonder: under certain conditions even particles smaller than one micrometer cannot escape. The principal component of HDC is the high-speed sprayer which assures the success of the whole plant. Its dimensions are small and its design has been well-known in engineering for a long time (formerly it was employed for other purposes). The sprayer, often called a Venturi tube, is, in principle, a convergent-divergent spray nozzle in which the cross section first decreases to a throat and then increases to the exit. Its constituent

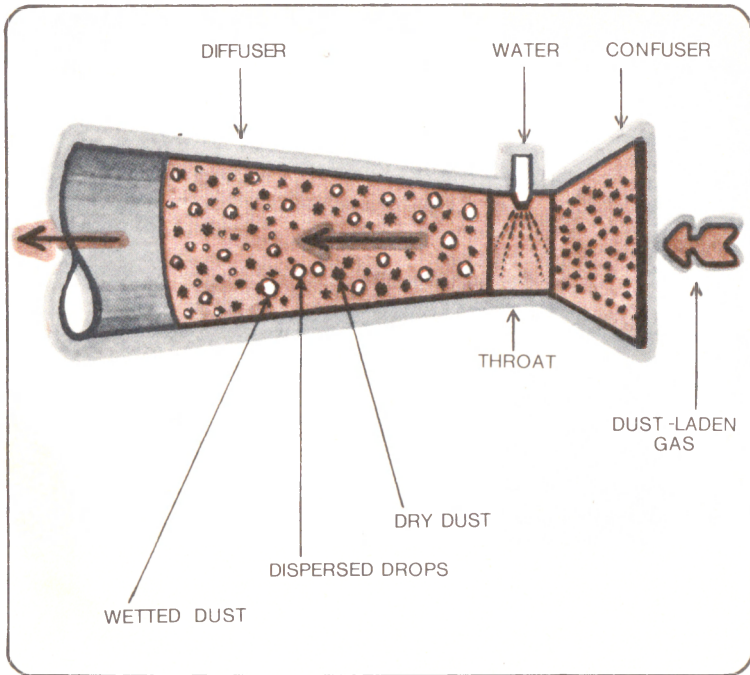


parts are (see the drawing) a narrowing cone (confuser), a small cylinder (throat) and widening cone (diffuser). Thanks to the strict proportions of these constituents and their shape it is possible, without exerting any additional force, to increase and then decrease the velocity of the gas flow. What for? To make the liquid work.

The gas enters the confuser and as it approaches the narrow cross section of the cone it picks up speed, otherwise it would have to stop in the throat. Here in the narrowest part of the sprayer it rushes along with the speed of a racer, and for this very reason the water is fed in here. It has to submit itself to the flow of the gas, but before this occurs it is broken up into drops of tenths of a millimeter in size. The motion of the gas is turbulent and the water is entrained in its swirling. Together with the gas the dust particles also swirl—a real blizzard with dust particles and drops of water whirling about! They inevitably collide and, therefore, the dust particles inevitably get wet. This process continues in the diffuser where the gas flow expands and moves more slowly and, therefore, the duration of contact between the liquid and the dust particles is increased. The maximum number of dust particles is involved in the process.

Of course wet dust particles are larger and heavier than dry ones and they are more readily and effectively precipitated from the gas flow. This is usually accomplished by a cyclone or electrostatic precipitator. These apparatus constitute a tandem with the high-speed sprayer, making a so-called high-speed dust-collecting plant. Sometimes an empty scrubber is, in addition, mounted upstream of the high-speed sprayer. Its function is preparatory.

Well, the advantages of wet apparatus are obvious. The particle-size range is quite wide. The “ability” of each apparatus is strictly defined, so it is easy to choose an appropriate one for definite conditions, taking into account the amount of gases, the particle sizes, the water and energy consumption (whether they are economically expedient or not). Besides, the collection of wet dust considerably improves the sanitary and hygienic conditions of transporting it: when tidying up, it is always better to remove dust with a damp cloth than with a dry one. Nevertheless, more and



**Tube sprayer**

more frequently, dry dust collectors are preferred to wet ones. It is hard to say whether wet-type equipment will be completely ousted by a dry one and when that will take place if at all. In any case the number of supporters of dry methods is constantly growing. Their arguments are very serious.

The negative side of any wet method lies in its very essence, in the need of water. At the time when such apparatus first appeared, the problem of fresh water did not exist yet. It seemed then that there would be enough of it for all succeeding generations. Alas, that was erroneous. Now fresh water has already become scarce. The main cause of this is the rapid technological progress which

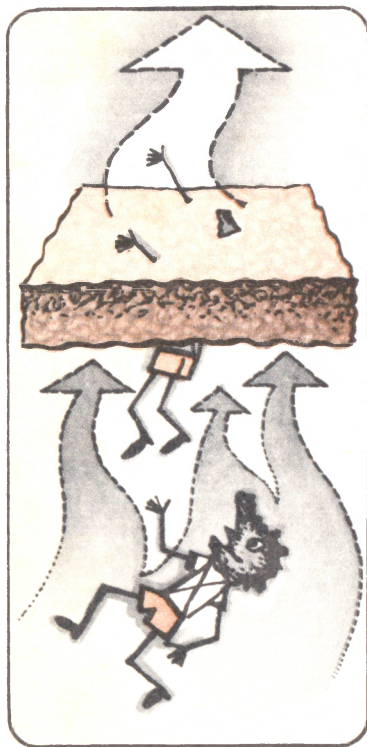
drinks water in enormous amounts. To produce only one ton of steel, 25 m<sup>3</sup> of water is required. A large portion of this water is spent in cleaning the ejected gases when a wet method is used. Incidentally, such methods are used for cleaning gases evolved in blast furnaces, converters and electric furnaces. For the purpose of economizing, the water, as a rule, is reused. Part of it, however, evaporates or escapes as spray. To reduce the losses incurred in this way, use is made of spray traps, but their efficiency is not, of course, 100%. And, therefore, part of the water has to be replenished from some outside source.

But there is another consequence of using a wet method. It produces waste water contaminated with harmful substances in amounts that considerably exceed the concentration permissible for effluents. You must admit that this is not logical: on the one hand we strive to protect the air from pollution, on the other hand we pollute the water. Of course, when necessary, waste water is purified. But purifying installations mean large capital investments and additional energy consumption. Is there any sense in raising the problem of waste-water clarification if dry methods can be used with the same effect?

It is this "if" that stands on guard of wet dust collection. It is not mere chance that blast furnaces, converters and electric furnaces are equipped with wet dust collectors—it is expedient to employ them when the temperature of the gases is high. Besides, in a number of cases harmful gaseous impurities can be removed only by means of wet processes. Still other advantages of wet apparatus are the stability of their operation, their simpler maintenance, the possibility of their being used to collect inflammable and dangerously explosive dust. All these advantages make it clear why it is still early to reject wet dust collectors.

## **A Reliable Screen**

*The way ahead is blocked.* We saw that it is possible to withdraw dust particles from the gas flow by forcing them to land, as in dust chambers; it is possible to isolate them with the aid of centrifugal



force or water, as in cyclones and scrubbers; it is possible... But is it actually possible to eliminate aerosols another way, by removing the dispersed phase from it? Yes, that is possible. And one of the most effective ways is by filtering it through various materials. The texture of these materials serve as a "barricade" that only gas molecules can pass. For most of the dust particles, passage is blocked. This is by no means a new method if you stop to consider that the word "filter" is derived from middle age Latin and means felt.

Quite unexpected, isn't it? However, up to the present time, felt is used for filtering. Why felt? Apparently, materials used for filtering must possess properties peculiar to them alone. For example, a sheet of lead cannot be put in the path of dust-laden gas because it is impenetrable not only

to gas but even for nuclear radiation. The principal property of filtering materials is porosity. There are pores between the fibers of wool; it is true that from the viewpoint of our ordinary notions, these pores are infinitesimal in size, their dimensions being equal to only tens of micrometers. Other fibrous materials are also porous. Look at a light through a piece of cloth or gauze. Pores are formed as a result of irregular or well-regulated interweaving of fibers. Fibrous materials form the basis of cloth filters.

Besides cloth filters, granular filters are in use. A granular filter is

a device in which the porous filtering layer is a bed of grains of some loose material such as quartz, sand and slag, coke and gravel, powdered metals. The efficiency of granular filters in which sand, slag, coke, etc. are utilized is lower than that of cloth filters, but they cannot be dispensed with if the gases are aggressive and cause corrosion or if it is impossible to reduce their temperature because on cooling the gases some valuable components in them can be condensed. Pores in layers of granular materials are as inevitable as between fibers. Place three balls side by side so that they are in contact with each other and you will see that a gap remains between them in the form of a triangle with concave sides. That is so in the plane of their centers. In space there are a great number of such balls (grains) and the gaps between them are the pores. The smaller the grains, the smaller the pores and, consequently, the greater the efficiency of dust collection. That is suggested by common sense and that's the way it is in reality.

A porous material, however, is not a sieve, because the smallest pores are many times larger than any of the particles that can be trapped. Yet gauze folded several times keeps infection off (microbes are comparable in size to dust particles), and the fabrics used in industrial filters can retain 99.9% of the dust particles, irrespective of their size. It does seem incredible that a particle a few micrometers in size, that can be seen only under a microscope, could not pass through pores that can be seen with the naked eye and are from several tens to several hundreds of micrometers in size. Nevertheless, it is a fact that it does not pass. A puzzle, isn't it? Yes, but one that has already been puzzled out.

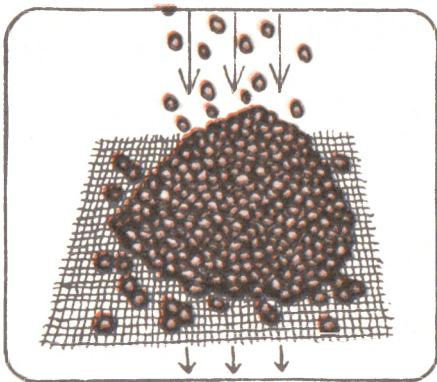
What happens, on a microlevel, when dust-laden gases encounter a porous material on their way? For the sake of simplicity, let us assume that this material is a piece of cloth. The dust particles entrained by the gas flow strive, together with the gas, to evade obstacles in the form of fibers and threads, but not all of them manage to do so. Part of the dust particles inevitably impinge upon the fibers due to inertia and remain on them. This mainly pertains to large dust particles which do not readily deflect from a straight path. The rest of the particles enter the pores and can be entrapped

there, depending on how close they are to a fiber. If the distance between a particle (i.e., its center) and a fiber is less than the radius of the particle, it comes in contact with the fiber and adheres to it, sharing the fate of those that have previously left the gas flow after impact with the cloth. This process of adherence is called direct precipitation.

Hence, the cloth entraps the dust particles as a result of inertia impact and direct precipitation. But is that all? The secret why porous filters are so efficient is that they mobilize almost all the physical mechanisms of dust precipitation with the exception, perhaps, of gravity. Molecular forces (Brownian movement) lead to the adherence of minute dust particles to the fibers and electric forces act on particles of any size if their electric charge is opposite to that of the fiber (here attraction is inevitable). As a result, the dust particles form a layer of dust intimately bound to the fibers. The cloth becomes more dense because the pores are reduced in size.

What happens next? The dust particles begin to weave "nets" for themselves. The second echelon of particles entering the gas flow is now retained not only on the fibers, but also on dust particles themselves, especially those in the pores. The dust particles cling to each other and it becomes almost impossible for new particles to break through the accumulated mass of dust. That is how the "baptism by fire" of the cloth takes place and now it is quite capable of sifting out even the most minute particles, because its pores have become commensurable with them. Using scientific terms, it can be said that it has acquired a very high degree of dust-collecting power.

Unfortunately, as the cloth is converted from a "clean" one to one covered with dust, another process proceeds simultaneously; its hydraulic resistance, i.e., its resistance to the passage of gas increases. At first the energy consumed in overcoming the increased hydraulic resistance is compensated for by the greater effectiveness of dust collecting, but there comes a moment when the cloth becomes unsuitable for filtering because of the large amount of dust on it. A golden mean is needed. But how can the best



working conditions be provided if a clean cloth is converted to a dust-laden cloth in tens and sometimes only in a few minutes? It is necessary to introduce into the technological process an operation called regeneration, the essence of which is to reduce the hydraulic resistance, in other words, to partly restore

the original filtering capacity of the cloth by removing the precipitated dust. For this purpose the cloth is either mechanically shaken or air is blown through it in the direction opposite to filtering (reverse blowing). When granular filters are used, sometimes the clogged-up layer is simply replaced. But whatever method is used, regeneration is an indispensable operation in the working cycle of porous filters, a cycle that consists of alternate retention of the dust and restoration of the filtering capacity of the porous material.

*Textile secrets.* Let us try to imagine for a moment that we are designers of cloth filters. We now understand, in the main, the essence of the filtering process and should find means for its realization. The first problem to solve is to select an appropriate fabric out of the many that are available. In order not to make a mistake, let us peep into the world of the textile industry.

We already know that the basis of cloth filters is a porous material the structural units of which are fibers. In the textile industry fibers are divided into natural ones, such as cotton and wool; rayon fibers obtained by chemical treatment of natural fibers, (for example, by treating wood cellulose with sulphuric acid), and synthetic fibers (nylon, orlon and many others) manufactured from various chemical products. Natural fibers have served mankind for many centuries. Synthetic fibers appeared in the 50s of our century

when chemistry got a firm grip on many industries. They appeared and very soon displaced wool and cotton, especially for industrial purposes. In fact, wool cannot withstand temperatures over 100°C, and cotton more than 70-80°C. In this sense the very first synthetic fibers to appear were promising: some of them (such as nitron) can work at 125°C. At present, there are fibers based on fluorine compounds, such as teflon or PTFE (polytetrafluorethylene) whose working temperature is twice as high, up to 260°C. As concerns heat resistance, only glass fibers can contest with such filtering materials.

Synthetic fibers are not merely heat resistant but they are also resistant to acids (as are glass fibers) and alkalies; that is why their advantage over other fibers is beyond any doubt. It is true, though, that glass fibers are very fragile and filters using them must be of a special design and require specific working conditions. In any case, the modern cloth-filter designer need not always provide cumbersome installations for precooling of gases like his predecessor in the "presynthetic" era did.

This, however, is not all that the designer must know about fibers. Textile workers distinguish between two chief categories: staple and continuous fibers. Staple fibers are comparatively short in length, from several tens to hundreds of millimeters long. They include such natural fibers as wool and cotton (woolen fibers are from 30 to 100 mm long and cotton fibers are up to 60 mm long). All rayon and synthetic fibers are continuous. They are produced by passing chemical solutions through very small holes called spinnerets, usually tens and hundreds of meters long, and if desired, can be a kilometer long. They can be cut up and converted to staple fibers.

What do we need all this information for? Up till now by cloth we meant, arbitrarily, any combination of fibers. This is not exactly so. There are three ways of using fibers for collecting dust.

The first way is using them in their primary form. In this case the gas will pass through a disorderly chaotic layer of fibers.

The second way is utilizing non-woven materials made from staple fibers (felt). Felt is produced from wool by the ancient



process of fulling—using moisture, heat, pressure and the ability of the fibers to be felt thanks to their flaky surface. That was how felt boots were made. Cotton and synthetic fibers are converted to a non-woven material otherwise: the fibers are arranged in regular rows and then stitched with thread or punched by toothed pins. Rayon fibers are hardly ever used for dust collecting.

The third way is using fabrics. Their manufacture is the most labor-consuming process: staple or continuous fibers are first spun into yarn (threads) and then cloth is woven by interlacing the threads on a loom.

Fabrics and non-woven materials are filtering competitors with equal rights; it is only necessary that they be suitable for the given working conditions. The design of the filter must always assure high efficiency and long service life of the filtering material under the specific conditions of the technological process. That means account must be taken of the gas composition, its temperature, volume, and also (last but not the least) the properties of the dust itself.

Reasoning proceeds approximately as follows: what gases have to be cleaned—process gases or ventilation gases? If process gases, non-woven material is less suitable. The dust in process gases is sticky and it would be harder to free the filter from it. Therefore, regeneration would have to combine power-driven shaking and reverse blowing. Non-woven materials cannot withstand such mechanical stress. That means cloth is needed. But what kind of cloth? As a rule, it is desirable to collect the dust at the highest possible temperature so as not to have to cool the gases by diluting them with air and thus increasing their volume. Pure wool and cotton are not suitable in such conditions. Besides, wool has recently been rejected because it is undeniably an excellent material for clothes. So what shall we choose? A synthetic fabric? It could be a fluorine-containing cloth, but that is still very expensive and therefore not economical. There are other synthetic fabrics that could be sufficiently effective. But glass cloth is even more heat resistant. Unfortunately, this cloth can withstand neither high speeds of filtration nor power-driven shaking. But what if the gases contain chlorine or some other aggressive components? In this case,

glass cloth is indispensable, providing the design of the filter is changed.

Let us now suppose that it is ventilation gases that must be cleaned. They contain less dust and it is more easily removed; sometimes reverse blowing is enough to regenerate the filter. In this case, a non-woven material is better because on regeneration cloth is restored completely and hence, its filtering capacity will be inadequate. Still if we are keen for cloth then a heavy two-layer cloth should be chosen.

Of course, the above discussion gives only a general, approximate idea of how fibrous porous materials are selected for filtering, but even so it is evident that the secrets of textile workers are of no small interest to designers of cloth dust collectors.

*A baghouse more than two stories high.* If you visited a metallurgical works and wanted to find out what a cloth filter was like, your guide would most likely take you to the most frequently used apparatus—a multi-sectional bag filter and he will begin his tale as follows:

“Look at this apparatus. It is made up of baghouses 7 m high, 7 m long and 2.5 m wide, which are made of 3 mm sheet steel. Each of them is a housing for cloth filters. The cloth in the filter is sewn to form a sleeve called a bag. Cloth is used in such a capacity not only in dust collecting. Recall, for example, fire hoses. Sleeves, however, are not the only form for filtering elements. They can be made in the form of pockets too.

If we climbed up to the manholes of a baghouse, we would see that they lead to a working platform where the condition of the bags and other units of the filter can be checked.

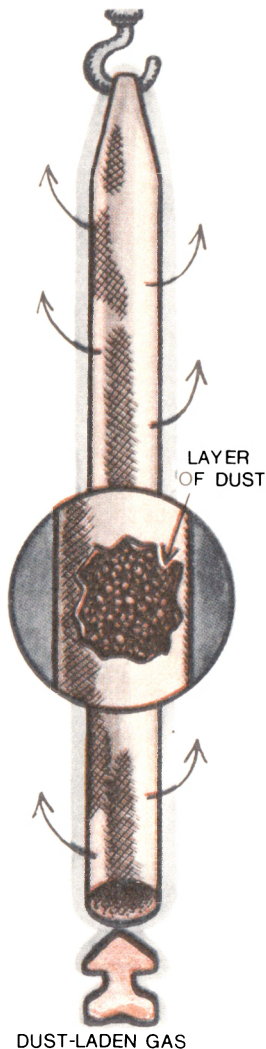
It is not by chance that the bags are made as sleeves for the filtering elements. It would be unwise to simply cover the cross section of the gas conduit with a piece of cloth—in only a few seconds it would be covered with a thick layer of dust and would have to be replaced. Even if a device for regeneration were found, it would not be able to lower the hydraulic resistance. Bags (sleeves) from this point of view are very convenient. Their surface area is great enough to allow large amounts of gases to pass through them. For example, the filtering area of one bag can be equal to 2 m<sup>2</sup> and

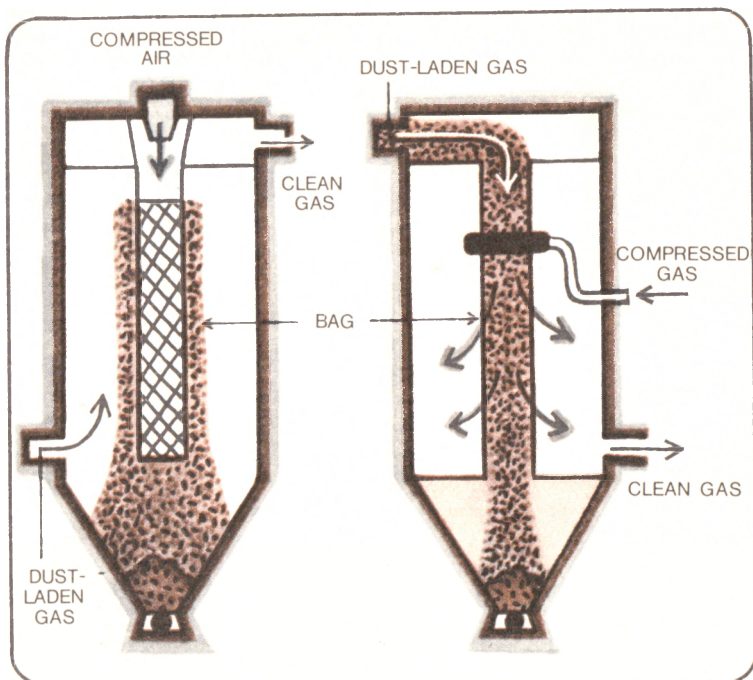
more. In general, in different filters the dimensions of the bags vary from 135 to 300 mm in diameter and from three to six meters in length. Up to 140 bags can be placed in one baghouse which, to facilitate its care, is divided into several sections, usually from four to six, the limit being ten.

Let us follow the guide to the top working platform. Before us will be disclosed a whole "forest" of bags arranged in staggered rows. They are hung by hooks from a supporting frame. On top they are covered with a metal hood, otherwise the bags would be gas flues and not filters. Sometimes use is made of bag filters in which the top of the sleeves are sewn up so that a loop is formed which is slipped over the frame. In both cases the frame is connected to a shaking mechanism.

Above the supporting frame there is a valve for clean gas and next to it an air blow-through valve. They work alternately. The blow-through valve is automatically switched on when the hydraulic resistance reaches a value that signals the necessity of reactivating the cloth. The shaking mechanism begins to work at the same time, jerking the bag upwards from six to ten centimeters. Regeneration of a section lasts several tens of seconds (up to one minute) after which filtering is resumed. Regeneration is carried out one section at a time.

Cloth bag





**Bag filters with active regeneration: by pulse blowing (on the left) and jet blowing (on the right)**

From the bottom working platform we can see a horizontal framework with holes for admitting the dust-laden gas. From this side the bags are open and attached to the framework by means of connecting pipes. At the very bottom of the baghouse there is a bin for collecting the dust removed during regeneration. The dust is let out of the bin by a worm conveyer. In this filter, as you see, twofold regeneration is provided for: power-driven shaking and reverse blowing. In it, synthetic fibers are utilized. Sometimes

a wool-containing cloth is used, whereas a few decades ago only pure wool was used for this purpose. The filtering rate, i.e., the speed at which the gases pass through the cloth, referred to the filtering surface, is approximately one meter per minute.

What other kinds of cloth filters are there?

A special filter has been designed for glass cloth because of its poor bending strength and resistance to wear. In such filters the bags are spaced far apart so that they do not touch each other when they bulge out during filtering. Regeneration, as a rule, is conducted by reverse blowing only. Sometimes the bags are pretensed with special coils. Because regeneration must be mild this time the rate of filtering is reduced to 0.3-0.5 m/min (i.e., one half or one third of the filtering rate when synthetic fibers or wool are used).

For process gases, and especially for ventilation gases, filters have been designed that are reactivated by jet and pulse blowers.

In filters equipped with jet blowers, compressed air is conveyed to the bag from its clean side with the aid of a carrier having holes or a ring-shaped aperture. The carrier moves along the bag and the dust precipitated on the opposite side of the cloth breaks up and falls away. In such filters use is made of a heavy two-layer synthetic fabric or felt. The filtering rate is from three to five meters a minute. Such filters are very effective when it is necessary to clean large quantities of gases with a small dust content.

In filters with pulse blowing, the dust-laden gases enter the bag from its outer side, i.e., filtration proceeds from the outside to the inside. So that the bags do not collapse, they are stretched over a wire framework. When compressed air is introduced in the process of regeneration, a high pressure is produced inside the bag as a result of which it is inflated and the dust falls from it into the bin. The regenerating pulse lasts 0.2 second. The rate of filtration is 1.5 m/min, i.e., greater than that of filters working with twofold regeneration.

The working principle of filters with pulse blowing and those with filtering elements having the form of pockets are similar—in both cases use is made of non-woven materials, and filtering is

carried out from the outside to the inside. For this reason, rigid frameworks are inserted in the pockets. Regeneration is accomplished by reverse blowing, sometimes by shaking the pockets a little. The advantage of pocket filters over bag filters is the possibility of increasing the filtering surface in the same space. The filtering material in them, however, wears out more quickly. Besides, they are harder to operate and the hydraulic resistance is greater than in bag filters. Other shortcomings, common to all cloth and fibrous filters, are the limited temperature, low corrosion resistance, the necessity of skilled maintenance, sensitivity to tar and moisture in the form of drops that can be contained in the gases. However, whatever disadvantages they may have, cloth filters are a reliable dust screen and their future use is very promising, all the more because the filtering materials are constantly being improved.

### **St. Elmo's Fire**

*The magic flask.* Unlike the other means of collecting dust, gas cleaning in an electric field is a relatively young method. It developed in the recent past and perhaps that is why the names of its originators did not get lost in bygone centuries but have been preserved for history. Along the path of its progress, the dates connected with the appearance of one or another event in the development and perfection of this method stand out like signs on a highway.

The year that electrostatic precipitators were "born" can be considered as 1600 when the English Court physicist, Gilbert, observed how smoke was precipitated due to the action of electrostatic forces. The same phenomenon was studied in 1745 by the famous American scientist Benjamin Franklin. Their observations, although very important for the future, merely ascertained the fact of precipitation and did not contribute anything substantial. They could not explain this curious phenomenon. That was disclosed at the end of the 19th century by the French physicist Coulomb. He derived the fundamental law stating the quantitative relationships of electrostatic attraction which made it possible not

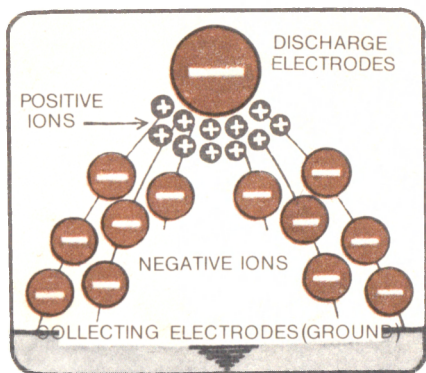


only to observe the collection of dust and mist but to realize this at will.

Subsequent experiments in an electrostatic field were conducted on a theoretical basis. In 1824 the German physicist Hohlfeld collected mist in a glass flask on inserting an electrically charged pointer into it, and in 1850 the French physicist Guitar repeated Hohlfeld's experiments with tobacco smoke. But since there was no serious dust-collecting problem at that time, Hohlfeld's and Guitar's experiments were forgotten for a quarter of a century. By the end of the 18th century the problem as a result of industrial progress became urgent. In 1884 the well-known English physicist Lodge resumed the experiments and soon after his investigations were completed, two engineers, Walker and Hutchings, continued them in a lead works in Wales (Great Britain). The experiments conducted there were not successful. Why? The question found no answer then. It came later. Nevertheless patents on various elements for electrostatic gas cleaning began to appear. The number of these patents constantly grew. In spite of this, two more decades passed before gas cleaning in an electric field was generally recognized.

The first functioning electrostatic precipitator with a capacity of 350 cubic meters an hour appeared in 1907, at the Pinole

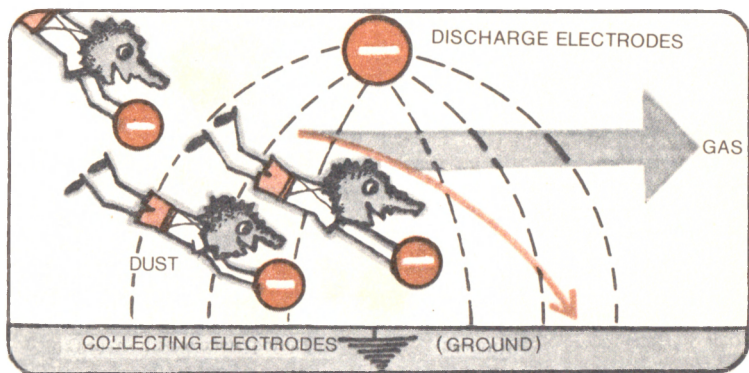
Ionizing dust particles in  
an electric field



gunpowder plant in the USA. The author of the apparatus used there was the American engineer Frederick Cottrell who subsequently played a big part in the development of electrostatic precipitation. The apparatus was intended for entraining sulphuric-acid vapors. This object was well chosen because particles of sulphuric-acid vapor cannot be detained by other means, for example, by cloth filters, because the particles are highly dispersed and very aggressive. The success of the apparatus at the Pinole works served as grounds for setting up a similar apparatus at the Selby Metallurgical Works, also in the USA. Its capacity was much greater (8 500 m<sup>3</sup>/h) and it worked normally for several years. The use of electrostatic precipitators spread widely in the 20s of our century. They began to be used not only in the United States but in Europe too, in different branches of the economy—in ferrous and non-ferrous metallurgy, in the cement and chemical industries, in power plants.

In the Soviet Union electrostatic precipitators also appeared in the 20s, immediately after the civil war. The first electrostatic precipitator was designed by professor Baimakov and was put into operation in 1925 at a plant in Leningrad. It was designated for collecting zinc oxide. In 1926, under the supervision of engineer B.P. Shneyerson, an electrostatic precipitator was set up (also





for collecting zinc oxide) at a paint-and-varnish plant in Yaroslavl.

*The invisible workers.* The distance between the theoretically based experiments of Hohlfeld and Guitar and the appearance of the first models of electrostatic precipitators is measured not only by tens of years. The flask with the charged pointer was actually merely a brilliant idea that still required practical realization. What suitable design was found for it? A design that is not too complicated but is at the same time quite bold. The flask with the charged pointer was converted into two sets of electrodes. One of them is made up of ionizing (discharge) electrodes (their prototype was the charged pointer); the other, of the dust-collecting electrodes (the flask in the experiments of Hohlfeld and Guitar).

What is each of the sets like? A discharge electrode in its simplest form is a round steel wire two-three millimeters in diameter. As a matter of fact, at the present time, besides electrodes of this type, use is widely made of thin conductors having variously shaped cross sections, such as triangular, square, cross-shaped; they may have the form of a spiral or resemble barbed wire. As to the collecting electrodes, they may be either metal or plastic tubes 200-300 mm in diameter, usually 3-4 m long or plates of the same length and from 3-4 to 10-12 m high. In the first case the

electrostatic precipitators are called vertical-round type in the second horizontal-plate precipitators. The discharge electrodes are either coaxially inserted in the tubes or placed between the plates, 100-150 mm from their surface. A tube or a pair of plates in combination with the discharge electrodes can be regarded as the working unit of the electrostatic precipitator. In one apparatus there are several tens or even hundreds of such units.

What are the electrodes for? To answer this question let us get them ready for work. This is done as follows. A high negative voltage (40-50 thousand volts) is applied to the discharge electrodes while the collecting electrodes are carefully grounded (connected to the earth electrically), thus imparting a positive potential to them. After that the air in the space between the electrodes actually "comes to life". An electric field is created. Billions of invisible electrons bearing a negative charge rush to a positively charged collecting electrode, bombarding the air molecules on their way. This process proceeds most intensively in the vicinity of the discharge electrodes, where the field intensity is especially strong. The electrons, on colliding with the air molecules, decompose them to form positive and negative ions and new electrons which, having accelerated in the field, begin to bombard new portions of air just as vigorously. What takes place is impact ionization, an increasing Townsend avalanch. Finally, there comes a moment when the degree of ionization is so great that a blue glow in the form of a corona appears around the conductor (that is where another term for the electrode—corona-forming electrode—comes from). The corona discharge (that is what it is called) is accompanied by a slight crackling and the fresh odour of ozone. In nature this phenomenon can be observed prior to a thunderstorm when a blue corona appears at the ends of highly raised pointed objects (for instance masts and spars of ships). In ancient times it was named St. Elmo's fire.

So the electrostatic precipitator is now ready for work. An electric field has been created, the corona-forming (discharge) electrode generates negative charges. Let us introduce dust-laden gas into the apparatus. The dust particles will inevitably come in

contact with the ions and electrons which impart their charge to them, like fire is passed on when we apply a burning match to inflammable objects. The particles with negative charges head for the collecting electrodes to take refuge there, and those with positive charges more to the discharge electrodes. But the number of positively charged particles is much smaller than that of the electrons and negative ions taken together. The dust particles are neutralized on the dust collecting electrodes and can be removed from them. But is it easy to do this? Let us turn back to times long past, to the experiments of Walker and Hutchings. Why did their experiments fail? Now we can answer this question. First of all, the electrical equipment was inadequate. And secondly... the lead dust itself was to blame. It upset all the calculations.

Why is that so? Only after tens of years did science find out that the electrical resistance of dust is of great significance for the effective functioning of electrostatic precipitators. Dust has even been classified in accordance with its resistance into three groups: low, normal and high-resistant dust. The dust of each of these groups on entering the space between the electrodes, shows its particular character. Ionization, the first process, proceeds in the same way for all three groups of dust, but precipitation and neutralization at the collecting electrode are specific.

The electrical resistance of lead dust is high. On reaching a collecting electrode, only the first layer of dust is readily neutralized. It becomes increasingly difficult for the negative charges of the following layers to do so because the previously precipitated layers do not let them pass to the positively charged electrode. What is the result? An accumulated charge raises the potential difference between the dust and the electrode up to several thousand volts and leads to their firm adhesion. Since the dust layer is not uniform and there are channels in it, back ionization and a positive corona can be produced in them and even a spark discharge. The dust layer is destroyed, the dust particles break away from the precipitating electrode and are carried away by the gas flow. The efficiency of the apparatus may thus be considerably reduced.

The first investigators and inventors of electrostatic precipitators knew nothing of this. Nor did they know that with the aid of a "little cunning" it was possible to drive the lead dust particles into the "trap". At the present time, gases that carry dust having a high electrical resistance are conditioned—atomized water or steam is introduced into them. On doing this the temperature of the gases falls and their humidity rises, both of which favor precipitation and neutralization of the dust. The dust covered with a liquid film becomes a better conductor, readily allows the electric charges to pass through and be neutralized and, therefore, can be easily removed from the collecting electrode.

The reverse is observed when the electrical resistance of the dust is exceedingly low ( $10^3$  to  $10^4$  ohm cm). Particles of such dust discard their charge too quickly and are just as quickly recharged. In this case the result is no better than in the previous one. The recharged particles are repelled by the identically charged collecting electrode and on encountering negatively charged dust particles are neutralized. They are carried away by the gas flow. It has been established that dust particles are precipitated most effectively when their electrical resistance is between  $10^4$  and  $2 \cdot 10^{10}$  ohm cm. As new dust particles from the gas flow approach the collecting electrode they discharge uniformly on its surface. However, in this case too, the dust accumulated on the precipitating electrode must be removed. It is done by shaking the electrode or hitting it with a hammer. The layer of dust splits up and falls into the bin from which it is carried away. The technological process of electrostatic precipitation is now over.

*The little secret of an air conditioner.* Thus, we have just with a stroke of a pen "breathed life" into electrostatic precipitators, and invisible ions and electrons propelled by a high voltage went to work to clean the dust-laden gases. If it were only as easy to do this in practice! Just as easy, for instance, as inserting a plug of an electric appliance into an ordinary socket. Alas, for electrostatic precipitators this is not so. They cannot work from the ordinary power-supply system which we use in our daily life. In this case, the alternating current and low voltage are unsuitable. A low voltage

fails to produce a corona and that means ionization will not take place. Periodic change of direction of the current results in disorderly motion of the ions. They will dash from one electrode to another, and together with them, the dust particles will not be able to find "refuge" and will be carried away into the atmosphere together with the gases.

To solve this problem, engineers devised a system of intermediate agents, consisting of step-up transforming substations which are either located separately or, for the sake of compactness, are mounted directly on the lid of the electrostatic precipitator. Without these substations the electrostatic precipitator is a still-born child. Of what apparatus is the substation composed? In the first place, a step-up transformer. Its purpose is to increase the voltage in the system to tens of kilovolts. In the second place, a rectifier. Its purpose is to convert alternating current to direct current, i.e., to set the electrons and the ions into directed motion. Industrial electrostatic precipitators use a current polarized negatively, as we have already mentioned; while air filters used for sanitary and hygienic purposes, air conditioners for example, employ a positive potential for the discharge electrode. Why? Because in this case much less ozone (which is harmful to the organism) is produced. By the way, electrostatic precipitators are indispensable accessories in air conditioners of many designs.

To obtain direct current polarized negatively use is made of selenium and silicon semiconductor rectifiers. They have replaced the cumbersome electromechanical rectifiers. A set of selenium and silicon plates that possess the marvelous property of allowing only electrons to pass through them, can be an invincible obstacle for charges of the opposite sign. But a direct current is still not all. The voltage must be sufficiently steady, i.e., not to rise so high that a short-circuit arc will arise and at the same time be high enough to ensure steady ionization, guaranteeing the collection of the maximum amount of dust particles. Things are complicated by the fact that the parameters of the gases ejected from metallurgical plants continually change: the temperature can fall, the humidity can rise, the dust content can increase or decrease, and the content

of sulphur dioxide in them can vary. All this changes the resistance of the medium, as a result of which the voltage varies and can jump beyond the permissible limits. In the first electrostatic precipitators to appear, the voltage was regulated by hand; fearing a breakdown, it was maintained at a level known to be low. Of course, the efficiency of the electrostatic precipitator was also low. In our days automation has come to help man. An automatic regulator of the voltage is the third indispensable participant of the trio of which the transforming substation is composed.

Well, what is the precipitator itself like? The sets of electrodes, of course, are not located in boundless space. They are contained in a housing made of steel, concrete, bricks, sheet lead or other materials, depending on how aggressive the gases are. A condition that is absolutely imperative is airtightness of the housing which can be rectangular or cylindrical in shape. Thanks to airtightness of the housing the gases do not escape into the atmosphere and do not pollute the surrounding air. Besides, in this way the safety of the attendants is assured as they are isolated from the high voltage.

Airtightness also assures minimum inleak of air into the housing, which could lead to a detrimental increase in the volume of the gases and decrease in the concentration of sulphur dioxide. Above or at the side of the electrodes there is a device for shaking them; and at the bottom, as you already know, there is a dust bin with transport facilities. In other respects there may be many variations in the design of the precipitators.

Electrostatic precipitators can be vertical and horizontal, depending on the direction in which the gases move; single-field and multiple-field; single-section and multiple-section. What sense is there in such a variety? To some extent it resulted from the evolution of these gas cleaners, which proceeded parallel with the development of industrial processes. They grew in scale and size. Single-section, vertical, single-field apparatus, such as those the first filters were like, are now used only when the amount of gases is not great and the content of dust in them is small.

Modern industrial electrostatic precipitators are horizontal, multiple-field and multiple-section ones. What advantages do they

have? If there are several sections, the precipitator can work continuously, and many industrial processes, in particular metallurgical processes, are continuous. The precipitator in such a process cannot be stopped but a section can be switched off. There are usually up to three sections in one apparatus. A separate field can also be switched off (there may be four of them or more). But several fields not only assure a continuous process, this also means better cleaning because the time during which the gas is in the cleaning electric field is increased. Taking into account that as the gas passes through the field its dust content becomes less, the distances between the electrodes in the fields are sometimes made different, reducing them downstream. Because of the necessity of providing several fields, vertical filters have been replaced by horizontal ones. Another difference in modern electrostatic precipitators is the use of plates for the collecting electrodes which makes it possible to arrange a greater number of electrodes in an equal volume. Thus modern apparatus are more compact and their efficiency is greater.

Does this exhaust the variety of designs of electrostatic precipitators? No, it does not. Those put in airconditioners differ from industrial ones not only in that the discharge electrodes are made positive. This precipitator has two zones. Charging of the particles and their precipitation are performed in two different zones. In one of them the discharge electrodes are located, in the other the collecting electrodes. The voltage applied in such precipitators is lower than that in industrial ones. There are also two-zone electrostatic precipitators in which the systems of electrodes are wire-mesh screens. The screen-ionizer works under a voltage of 13 000 volts, the screen-precipitator under a voltage of 7 000 volts. Such screen precipitators are used to free the air of industrial premises from dust and other particles, including pollen, bacteria and even some kinds of virus.

There are also two different technological varieties of electrostatic precipitation: the dry and the wet process. In the first case the temperature of the gases is sufficiently high, higher than the dew point (condensation temperature) of water vapor and other vapors

present in the gases. In the second process the gases are wet, and wet dust is collected. In this case the dust is washed off the electrodes.

An electrostatic precipitator is a complicated apparatus demanding skilled handling. But this is more than compensated for by its advantages: first of all the possibility of removing over 99% of highly dispersed solid particles, liquid drops and mists even when several tens and even hundreds of grams are contained in one cubic meter. The temperature of the gases being cleaned may be 450°C, and lately attempts have been made to raise this temperature limit. The gases being cleaned can contain highly aggressive gaseous components, for example, sulphuric and sulphurous anhydrides of a concentration of tens of per cent. In this case it is only necessary to select appropriate materials for the housing, electrodes and other elements of the electrostatic precipitator to ensure its successful functioning. At the present time the electrostatic precipitator is one of the most perfect apparatus available for collecting dust, and therefore is widely used in many branches of industry.

### **To Be or Not to Be?**

Try the following simple experiment. Take an earthenware flowerpot and pour a little water into it so that it does not leak out from the hole at the bottom. Before your very eyes the earthenware around the hole will begin to darken, resembling an oil stain spread on paper. The dark ring will gradually increase in size as the water penetrates into the mass of the pot. Well, where water can penetrate, air can too. Earthenware can "breathe". Why? Because it is a porous material. In this respect it is akin to cloth. Like cloth it is used as a filter. According to the classification adopted in dust collecting, such ceramic partitions are referred to as rigid, granular, porous filters. Another type of granular filter are those composed of loose grains. Both are intended for hot filtering, when the gases need not or cannot be cooled. Some of these filters can withstand aggressive media, sudden changes in pressure and great mechanical stress.

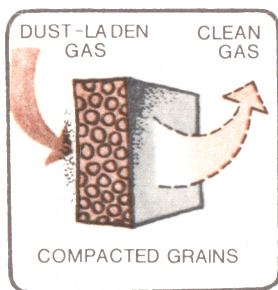
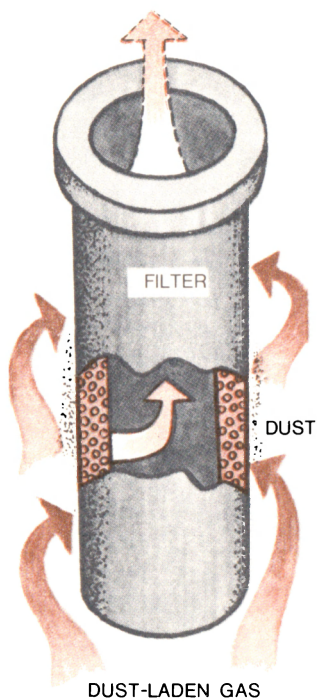


Granular filters, especially those with loose grains, vary in design. One of them consists of several metal containers with perforated bottoms placed in a chamber. Each container is a section that can be at wish removed from the process of filtering. The containers are fixed on springs and connected to vibrators; they are loaded with sand or some other loose material to form a layer 1.5-2 m high—as tall as a man. The grains are 1-2 mm in size. When the filter is working, the same sequence of events takes place as in cloth filters, and regeneration is also performed by reverse blowing, but this time in conjunction with vibration instead of shaking. Regeneration is carried out section by section like in the case of cloth filters.

When analyzing and evaluating the performance of granular filters they are not accidentally compared with a cloth filter, because cloth filters are reliable apparatus that proved to be good at work. Are granular filters, in particular loose-grain filters, superior to this standard? The temperature of the gases cleaned in them is usually 350-400°C. That exceeds the permissible temperature for the most heat-resistant cloth by 100-150 degrees. And what about their efficiency? Up to 99%. Quite an impressive figure, but, unfortunately, granular filters are suitable only when large particles have to be separated from the gas flow, such as those resulting from the mechanical processes occurring in crushers, screens, dryers etc. Such equipment is usually employed in the production of fertilizers and cement.

Why is the performance of granular filters so limited? First of all, the size of the precipitating element, in this case of the grains, is important. Compare the diameter of a fiber in cloth which is approximately 35  $\mu\text{m}$  with that of a grain which is equal to 1-2 mm, i.e., 30-60 times larger. According to aerodynamics, the larger the precipitating element the less effectively can it retain the dust particles especially the small ones. The dust particles in this case easily avoid the obstacles (grains). Besides, the pores between larger bodies are larger in size and as the grains of sand are loose, the gas on flowing past them draws them apart, letting the small dust particles pass through.

It would seem that the rigid granular filters mentioned at the



beginning, must be more effective. Is it so in fact? Let us acquaint ourselves with how they are made. First of all, it should be pointed out that besides rigid ceramic filters, rigid filters can be metal-ceramic (made of powdered metals) and made of other materials. Rigidity is achieved by sintering or cementing the grains at high temperatures, preliminarily compressing or sometimes rolling them. As a result, a porous framework is formed in which the pores can practically be the same size as those in cloth. The above refers primarily to metal-ceramic filters. To manufacture them use is made of powders in which the grains are comparable in size with fibers (the diameter of finely powdered metal is about  $35\text{ }\mu\text{m}$ ). But in rigid ceramic filters the pores are also sufficiently small to produce a screen effect, i.e., to remove the dust particles from the gas flow.

The efficiency of rigid granular filters approaches that of cloth filters. Rigid filtering partitions are made in the form of cylindrical tubes (cartridges), tiles or thick sheets. During filtration the particles being separated are precipitated on the outer surface of the filter or in its

**Rigid porous granular filter**

pores. Compare: either on the fibres of cloth or in the pores. Regeneration is performed by reverse blowing only, as shaking of rigid filters is ineffective. Compressed air blows the particles out of the pores, breaks up the layer of dust on the outer surface of the filter and throws it down from there. Notice, not simply air from a ventilator as in cloth filters, but compressed air. What is the result? The efficiency of the filter exceeds 99% for fine dust, and at a temperature of 300-600°C. Isn't it a worthy competitor of cloth filters? And if you take into consideration that metal-ceramic filters can be made of powdered corrosion-resistant steels, the scale pan containing the merits of granular filters will be overfilled. But let's not be in a hurry.

Rigid granular filters have their Achilles' heel. Their vulnerable spot is the design of their filtering elements and their limited dimensions. Ceramic cartridges are 50-80 mm in diameter and 0.5-1.2 m long. Because of the relative fragility of ceramics, the walls have to be 6-10 mm thick and sometimes even thicker. Metal-ceramic cartridges are larger: 80-100 cm long with thinner walls, 2-5 mm thick. Cylindrical tubes made of metal ceramics are welded endwise, building their height up to a few meters. But what are these dimensions in comparison with bags six meters long and up to 300 mm in diameter. The capacity of cartridges of rigid granular filters is correspondingly smaller. Besides, when the filtering surface is large, their fastening is very complex. Regeneration is also a problem: it is necessary to use compressed air which must first be freed from drops of water and oil. In addition, the filter becomes clogged up with dust that cannot be removed. The economic aspect must also be taken into consideration: metal-ceramic filters (they possess the greatest merits) are costly.

The fate of rigid granular filters depends on which of the pans of the scale is heavier, the one containing the doubtless advantages of these filters or the one containing their no less obvious disadvantages. Time alone will show whether these filters will be widely used or not, that is answer the question "to be or not to be?"

## In the Language of Mathematics

When writing about the physics of the various processes of dust collecting we constantly caught ourselves thinking that words are often inadequate for expressing the interdependence between the variable conditions of the gases and the dust and the design of the dust-collecting apparatus. It seemed to us that the language of formulas was more suitable for this purpose: it is simpler, more concise and much more expressive. Formulas describe a phenomenon precisely, giving the necessary quantitative characteristics involved. That is why we decided to let the reader have a "taste" of mathematics, which no science can do without. Even such a purely humanitarian science like linguistics has concluded an alliance with mathematics. So much the more, technology and engineering cannot dispense with it. The formulas we will give below are not complicated; they cannot be employed to determine the degree of purification of gases; but using them, it is possible to judge how it rises or falls under varying working conditions or with an increase or decrease in the precipitating forces. It is these very forces that are considered in the formulas characterizing the physical mechanisms of dust precipitation.

What mechanisms are we referring to? They are our old acquaintances. There are six of them—six "whales" which support modern dust collecting. The simplest is the separation of dust by the force of gravity. Recall the dust chambers: they use ordinary gravity, only in an enclosed space. In this case the force acting on the dust particles is the same as that which acts on any body in the Earth's space:

$$F_g = mg$$



Here  $g$  is the acceleration of free fall which is constant for a given region of the globe, and  $m$  is the mass of the body, in our case of the dust particle. The greater the mass the greater the force of gravity. The conclusion that can be drawn for practical purposes is that the larger and heavier the particles the sooner they land and

are separated from the gas flow. What we have spoken of so many times is confirmed mathematically.

The same conclusion can be drawn from the formula characterizing the action of the centrifugal force produced in cyclones and multicyclones by whirling the gas flow:

$$F_c = mv_g^2/R$$

In the numerator,  $m$  is the mass of the particle, and  $v_g$  is the circumferential velocity of the gas flow; in the denominator,  $R$  is the radius of the cyclone.

What does this formula indicate? We repeat once more. First of all that the efficiency of dust collecting grows with an increase in the mass of the particle. And what if this mass is constant? In this case to increase the centrifugal force it is necessary either to increase the speed of the gas flow or to decrease the radius of the apparatus; that is just what was done when cyclones were replaced by multicyclones. And, as a matter of fact, both things can be done at the same time.

The third mechanism of separating dust from the gas flow is the collision of the particles with the precipitating element, in other words—inertia impact. In cloth filters, on colliding with threads or fibers the dust particles “drop out of the game” just as they do in scrubbers on colliding with drops of liquid. When we spoke of this previously we simply used our common sense. Below we give the quantitative expression of the force of inertia impact:

$$K_i = \frac{1}{18} \frac{\rho_d d^2 v}{\mu D}$$

In this expression  $d$  is the diameter of the particle;  $v$  is the speed of the particle with respect to the precipitating element (if it is at rest,  $v = v_g$ , i.e., the speed of the gas flow);  $\rho_d$  is the density of the dust;  $\mu$  is the viscosity of the gas;  $D$  is the diameter of the precipitating element.

And again the same conclusion can be drawn. The larger the particles, the more readily they are caught in the “trap” set for

them. But that is not what is of the greatest importance in the above formula; the main thing is the relation between the force of inertia impact and the size of the precipitating element. The smaller this element, the better. Filters made of thin fibers and fine grains are much more effective than coarse filters. For example, a fiber or drop  $4\text{ }\mu\text{m}$  in diameter collects dust 5 times more effectively than a  $20\text{ }\mu\text{m}$  fiber or drop as  $20 \div 4 = 5$ .

Direct precipitation is the fourth mechanism for separating dust from the gas flow. It works only when the dust particle passes by the precipitating element (a fibre or thread) at a distance less than its half size measuring from its center. Collision is then inevitable. The intensity of direct precipitation depends on the ratio  $d/D$ , where  $d$  is the diameter of the particle and  $D$  is the diameter of the precipitating element. Again we come to the conclusion, that the larger the particle and the smaller the precipitating element, the greater the intensity of precipitation. Just as in the case of inertia impact.

We have already, and not once, spoken of such a mechanism as diffusion. We spoke in particular of the Brownian thermal diffusion when moving molecules may push the dust particles to the surface of the precipitating element. The intensity of diffusion can also be expressed quantitatively:

$$K_D = kT/3\pi\mu v_g D$$

The meaning of all the symbols in the formula, with the exception of  $T$  and  $k$ , is the same as in the previous formula;  $T$  is the absolute temperature, and  $k$  is Boltzmann's constant. Diffusion is perhaps the most complex mechanism which is affected by the greatest number of factors. The chief one is the temperature. The higher the temperature, the greater the movement of the molecules and the bigger the chance that precipitation will occur; but that this should happen to the greatest degree, the size of the particles and that of the precipitating elements, the speed of the gas flow and the viscosity of the gas must all be small. We have not accidentally repeatedly pointed out that *small* particles are primarily separated out from the gas flow by the diffusion mechanism.

Finally, the last mechanism utilized in dust-collecting apparatus is caused by the action of an electric field. As has already been said, it is produced by supplying a high negative potential to the ionizing electrodes. The force with which an electric field acts on a charged particle is determined by the formula:

$$F_e = q_{\max} E_x$$

Here  $q_{\max}$  is the electric charge of the particle, which in one and the same conditions increases with an increase in the diameter of the particle;  $E_x$  is the field intensity (in the  $x$ -direction).

Once more: the larger the particle, the more easily it is collected. That is the rule, the only exception being in the case of diffusion.

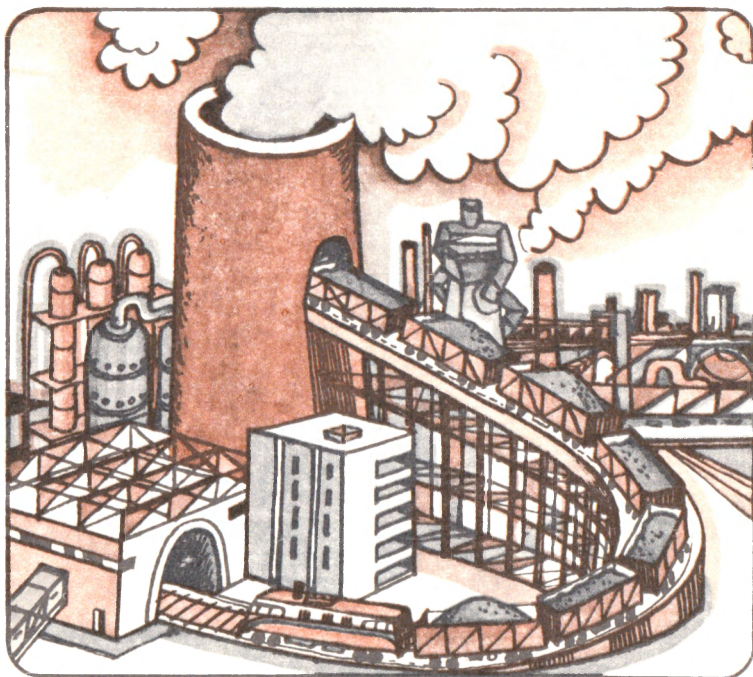
That is how the physical fundamentals of dust collecting look like written in the language of mathematics.

## **Ultimate Destination**

So the dust particles have been precipitated in a dust collector. But is this the end of our story about the destiny of the dust? Do not be in a hurry. From this moment, it can be said, its second life has begun; the dust can be converted from a pollutant of the surrounding medium to a valuable raw material. It must only not be lost on its way from the dust bin to the metallurgical plant in which it will be employed in its new capacity.

When the dust is collected in a wet apparatus the unloading of the bin and subsequent transport of the dust do not present any serious difficulties. The wet dust particles, in the form of a viscous liquid, gather at the bottom of the apparatus from which they are let out into a settling tank, by gravity or with the aid of a pump. Then, in the form of a slime, it is conveyed to a metallurgical plant for further treatment. No repeated dust formation takes place.

Dry methods of dust collecting are quite another matter. Despite all their advantages over the wet methods, in this aspect, they are disadvantageous. Many problems arise. How is the dust to be removed from the bin? It does not take great imagination to



picture what would occur if, let us say, a dump truck were driven up to the bin and the outlet for discharging the dust were opened. The lightest puff of wind would be sufficient for the fluffy mass to go up in a cloud into the air, canceling all the efforts spent on collecting the dust. It will go off into the atmosphere, never to return. The situation would be just as bad if we wanted to transfer the remnants of dust (remnants they will be indeed) from the dump truck to a metallurgical plant. But this is not all yet. Before the dust removed to the plant has time to be subjected to metallurgical treatment, the gases will carry away its finest particles and the process of collecting it will then have to be repeated.



In modern dust-collecting practice, of course, such methods of unloading and transporting are not employed. It would just be too absurd. What is done is altogether different. Transportation is accomplished in airtight facilities: either by screw or scraper conveyers or by pneumatic transport, when the dust is carried along in a stream of air just like the “young”, primary dust was carried in a stream of gases. When the dust reaches its destination, it is admitted together with the air into a cyclone or cloth filter which differ in design from those used for the primary dust. The difference is due to the fact that the concentration of the secondary dust in this case is very high (hundreds and thousands of grams per cubic meter). The dust settles in the bin of the secondary dust extractor and the air either escapes into the atmosphere (that is undesirable) or is reused in the pneumatic-transport cycle.

And how is the metallurgical plant charged with this dust? First of all, it is subjected to lumping. Two methods for doing this are most widespread: briquetting and granulating. In briquetting, the dust is compressed, first wetting it with a binder. In some cases water is used for this purpose. In the second method, the dust is placed in a large pan resembling a frying pan and is pelletized, i.e., converted into balls a few millimeters in diameter. Here water or some other binder is also added. As a result, the metallurgical plant is charged with briquettes or pellets. The dust has reached its ultimate destination.

### **“The Taming of the Shrew”**

From ancient times a Greek myth has come down to us about Sisyphus, a Corinthian king doomed forever in Hades to roll uphill a boulder which always rolled down again. Dust collecting is not a Sisyphean task, but in some cases, unfortunately, such a comparison does suggest itself. Well, this myth comes to mind when looking at what happens in furnaces with a fluidized bed for calcining copper concentrates, of which we have already spoken. The furnace is a quite up-to-date, highly efficient and economical

plant, but the fate of its dust-collecting apparatus is not enviable. Daily this furnace calcines an average of 500 tons of concentrate. The output of calcine is only half of this, 250 tons. Where does the rest of the concentrate go to? It escapes from the fluidized bed together with the gases. At the best it is only a half. It can be even more. The dense screen of the dust-collecting facilities obstructs the passage of dust particles and they are returned for metallurgical treatment. But will this take place? Again half will be carried away by the gases. We will not count how many times the dust returns to the furnace before it is completely converted to calcine. That would be too complicated. It would be necessary to take into account how much escapes into the atmosphere and the losses during charging and discharging as well as other leakage. There is only one answer—many times. You must admit that there is something of Sisyphean labor in this. The consequences of such repeated action are not as innocent as may seem: the output of calcine is reduced, the consumption of concentrate is increased as well as the wear of the dust-collecting apparatus and finally, the environment is polluted. In each cycle about 1% of the dust escapes into the atmosphere, and in absolute figures this is a large quantity.

You have already got accustomed to the idea that dust and harmful gases are inevitable “co-travellers” of metallurgy. This is indeed so. But can't the amount of dust carried away be limited to some extent at least? This is not just a rhetorical question; the answer to it has been and is still being searched. Some results have already been achieved.

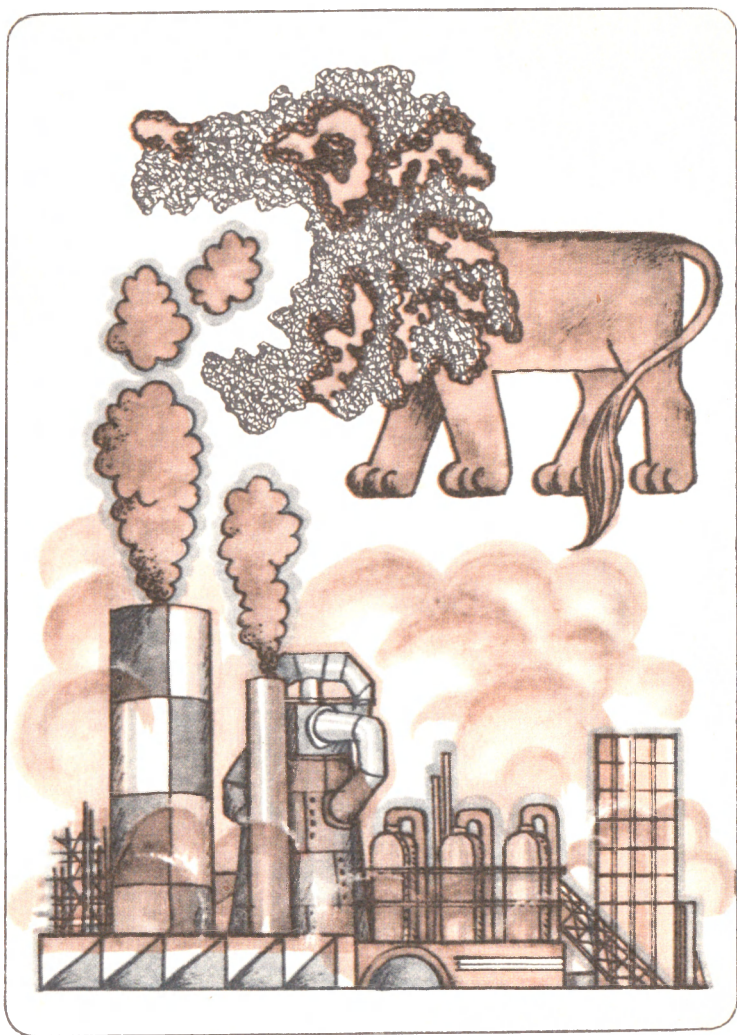
What measures are taken for preventing the dust from being carried away, or as this operation is called, for dust suppression? That depends on where the dust is generated—on whether it is mechanical or sublimated dust. This difference is important for dust suppression. It is comparatively easy to suppress mechanical dust. Thus, dust formed during transportation is sprinkled with water. A shower is set up over the places where transshipment, loading and unloading of materials is carried out. A curtain of water intercepts the passage of the dust particles and they obediently settle down. Jet sprayers similar to the ones used in scrubbers,

supply the water. They are automatically turned on when the transported material is in motion. If the conveyer is at rest, no dust is raised above the material and, hence, no water is needed. Is this method efficient? A tenth of the dust is returned to the total mass of material being handled. This amounts to thousands of tons. That is how mechanical dust is "tamed".

To tame fumes is much more difficult; indeed you cannot pour water into a metallurgical plant. Soviet researchers have proposed a method for dust suppression by means of a high voltage, that has proved to be effective. It is used in the metallurgy of non-ferrous metals, in particular, for suppressing dust evolved in calcining furnaces with a fluidized bed. A pointed grid is inserted (through an insulator) into the furnace from the top. It is fixed at some distance from the fluidized bed and is supplied with a negative potential 30-50 kV high. What happens is the same as what occurs in electrostatic precipitators. The dust particles carried away by the gases, on approaching the grid points are imparted a negative charge and return to the fluidized bed. In what proportion? Out of the 250 t which is carried away in the absence of a dust suppressor, 100 t remains in the furnace, i.e., the escape of dust is reduced by 40%. That means the amount of calcine produced is increased by 100 tons.

In the iron and steel industry research on the suppression of dust emission from converters with the aid of ultrasonics is now being conducted. The dust content in the ejected gases is reduced in this case by 30-40%. As elsewhere where it is practiced, there are no radical changes in the technological process due to dust suppression.

The search for methods of "taming" dust is being carried on.



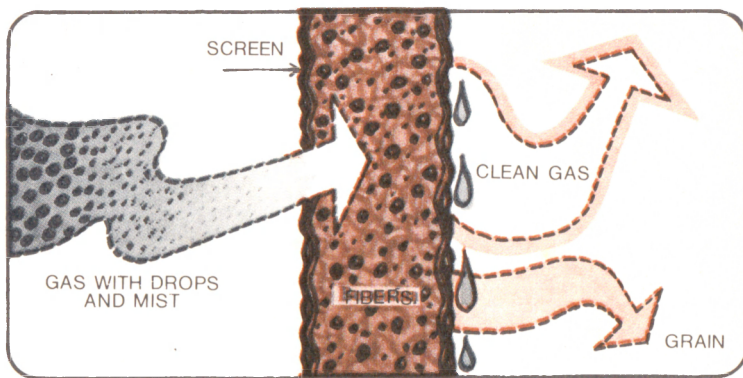
## **DROPS..... IN A SIEVE**

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Particles of dust and drops of rain. A solid and a liquid. One would think there could be no similarity between them—only that it is equally unpleasant to find oneself in a dust storm or in a pouring rain accompanied by wind. Well, such a situation in itself contains a kernel of reasoning for understanding the essence of aerosols: our skin can sense the presence of a dispersed phase in the gas-carrier (in the air). Remember it can be a solid (fume) or liquid (drops, mist). And the gas-carrier, as you know, can not only be air but also metallurgical gases. We already know that these gases can contain a considerable amount of dust. But can they contain a liquid dispersed phase? Yes, they can. But it is not always present—only when vapors are precipitated from the gas flow, for example, water vapors. And if sulphur dioxide is present in the gases it will dissolve in the water, forming a mist of sulphuric acid. This is the liquid dispersed phase to be removed from the gases.

How is a drop or mist separated from the gas flow? To understand this, it is necessary to broaden our idea of the similarity of solid and liquid dispersed phases. Dust particles on colliding with each other conglomerate, while drops coalesce into larger ones. Both are detained on various surfaces by adhesion. In motion, both phases acquire the speed of the gas flow. Therefore, inertia impact can take place. Finally, both particles of dust and drops are exposed to the action of moving molecules (Brownian movement). In the face of such similarity, the differences lose their significance.

All the properties of particles, all the methods for precipitating them which we have described, are used in dust collectors. But if the similarity between the solid and liquid dispersed phase is so great, then it can be assumed that these apparatus are suitable for "trapping" sulphuric-acid mist. The assumption has been put into practice. For freeing gases from drops and mists of sulphuric acid use is made, in the main, of fibrous filters, and, to a smaller extent, of wet electrostatic precipitators. The liquid phase is also entrapped in high-speed scrubbers and granular filters. But the latter are not



Fibrous drop collector

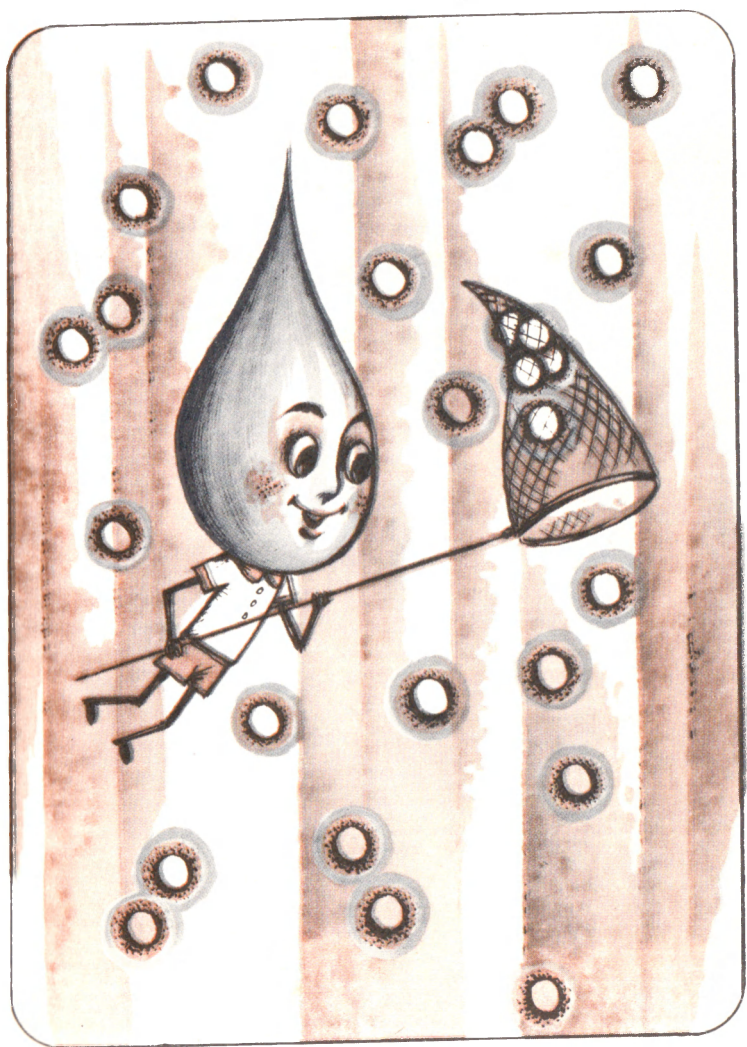
very effective for sulphuric-acid mist which is highly dispersed.

Fibrous filters are the most effective drop collectors. In the case of sulphuric acid, chemically stable fluoroplastics such as polytetrafluorethylene (PTFE or teflon) are used.

The design of fibrous drop collectors is not very complex. A layer of fibres is placed between the outer and inner surfaces of a perforated hollow cylinder also made of chemically stable materials. The gas carrying the drops passes from the outer surface through the filtering layer and the clean gas is withdrawn from the cylinder (drop collector). The liquid drips off by itself without forced shaking (as in the case of dust collecting).

It is well-known that water cannot be retained in a sieve, but the fibres keep the drops of liquid from escaping into the atmosphere. Practically 100% of drops having a diameter over  $3\text{ }\mu\text{m}$  are retained; and 99.7% of smaller drops. The resistance to the passage of gas usually reaches 1.5-2 kPa (150-200 mm of  $\text{H}_2\text{O}$  column).

In electrostatic precipitators the same thing happens to the drops as to dust particles. They acquire a charge and under the force of an electric field find themselves on the collecting electrodes from which they drip off.



## MOLECULES VERSUS MOLECULES

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### A Second Vocation of Scrubbers

The macro-world and micro-world... Recall the difference between them: dust particles, micrometers or parts of a micrometer in size, have properties that differ from those of larger bodies. And what about the micro-world that is invisible to the naked eye? What is it like? Is it uniform? By no means. In this micro-world even the finest dust particles are Gullivers in the land of Lilliputs, i.e., of molecules, the smallest particles of an element or compound. Molecules are from 5 to 15 angströms in size, and one angström is ten thousand times smaller than a micrometer ( $1 \text{ \AA} = 10^{-10} \text{ m}$ ). That means a molecule is about that much smaller than a particle of sublimated dust. In the macroworld, for example, that is the difference between a wooden ruler used for measuring fabrics and a 10-kilometer running or skiing track. No wonder prefixes were thought up for fractions and multiples of measuring units: they facilitate the comparison of commensurable magnitudes and the estimation of dimensions of objects that differ by several orders of magnitude. This explains, moreover, the appearance of such a unit as an angström—even a micrometer was too large for measuring the distance between atoms, the radii of atoms and the size of a molecule. The International System of Units (SI) uses for these purposes a unit called a nanometer which is a billion times smaller than a meter.

Why have we turned our attention to this? Because even in case one hundred per cent of the dust is collected, it does solve the problem of dust cleaning. It is, after all, only the dispersed phase that is collected. But what about the containing medium of the aerosol, the gas-carrier itself? Is it so harmless and useless? Oxides of nitrogen, sulphur dioxide, chlorine, fluorine, carbon monoxide and phosgene—that, by far, is an incomplete list of the components of metallurgical gases, and all of them are more or less toxic. There is no need to emphasize the fact that they must be removed from



the gas and either rendered harmless or utilized, before they enter the smoke stacks and through them escape into the atmosphere.

But how can this be done? Dust-collecting apparatus, with only one exception, are crude and helpless: molecules pass through them like through a sieve. Molecules are so small that gravity, inertia, and electrostatic forces are of no avail. Molecular forces can be opposed only by commensurable ones. Equals versus equals. Molecules versus molecules. To be more exact, molecular forces versus molecular forces. The problem is reduced to activating these forces in the substances used to retain the gas molecules that are harmful or contain valuable products. And here to our aid comes such a process as sorption. Gases in contrast to dust particles cannot be collected, they must be absorbed or adsorbed. Sorbents can be liquid or solid substances. Both are endowed with a remarkable selective power; in other words, they can withdraw from a mixture of gases the one we want to extract. Of course to achieve this, the proper sorbent must be selected.

In *absorption*, the gas penetrates into the body of a liquid or solid. For liquids this process is based on the ability of the substance to dissolve the gas; the gas molecules are uniformly distributed among the molecules of the liquid. The quantity of gas that can be absorbed by a given liquid is limited; it depends on the composition of the gas and the liquid and on their structure. The closer the nature of the substances, the greater the solubility: "like is dissolved by like". Let us take water, for instance. Hydrogen chloride, hydrogen fluoride and ammonia readily dissolve in it: hundreds of grams can be absorbed by one kilogram of water at 0°C and atmospheric pressure. Oxygen, nitrogen and carbon monoxide are only slightly soluble in water—only tenths and hundredths of a gram per kilogram. Chlorine and sulphur dioxide are moderately soluble. Hence, it is apparent that water is the best absorbent for ammonia and hydrogen chloride, whereas it is practically impossible to extract carbon monoxide with it.

How does absorption proceed? The first condition, one that is indispensable, is that the gas and liquid come into contact with each other; only then the molecular forces begin to act. But contact

alone is not sufficient. The concentration of the gas above the liquid must be high enough, while its concentration in the liquid must be as low as possible. In this case both the partial pressure\* and the difference in the concentrations of the given gas in the gaseous phase and in the solution, necessary for absorbing the gas, are attained. Both factors compose the driving force of absorption, i.e. the force that compels the gas to penetrate into the liquid. The greater the partial pressure and difference in concentration are, the more intensively the liquid sucks up the gas, absorbing its molecules. This process continues until equilibrium sets in, in other words, until a state of balance is reached between absorption and liberation, i.e., an exchange of molecules between the gas and liquid. This balance is not upset because as many molecules leave the liquid as return to it. Such an exchange continues as long as the absorbent (liquid) and absorbed substance (gas) are in contact.

Absorption proceeds more efficiently with greater contact surface; there are more chances for contact between the gas molecules and those of the liquid. The effect of another factor, the temperature of the liquid, is of no little importance. It is sufficient to recall with what force a cork flies out of a bottle of carbonated liquid if we forget to cool it beforehand, for it to become apparent that more gas dissolves in a colder liquid. We must remember all these conditions when selecting absorbents, designing apparatus for absorption, and operating these apparatus if we wish to achieve effective gas cleaning.

So, as we know, the first indispensable condition is intimate contact of the gas with the liquid on as large a surface as possible. Such contact is provided for by gas absorbers. We have already pointed out that among dust collectors that are incapable of extracting molecules from the gas flow there is one exception—the scrubber whose second vocation is gas cleaning. This is explained

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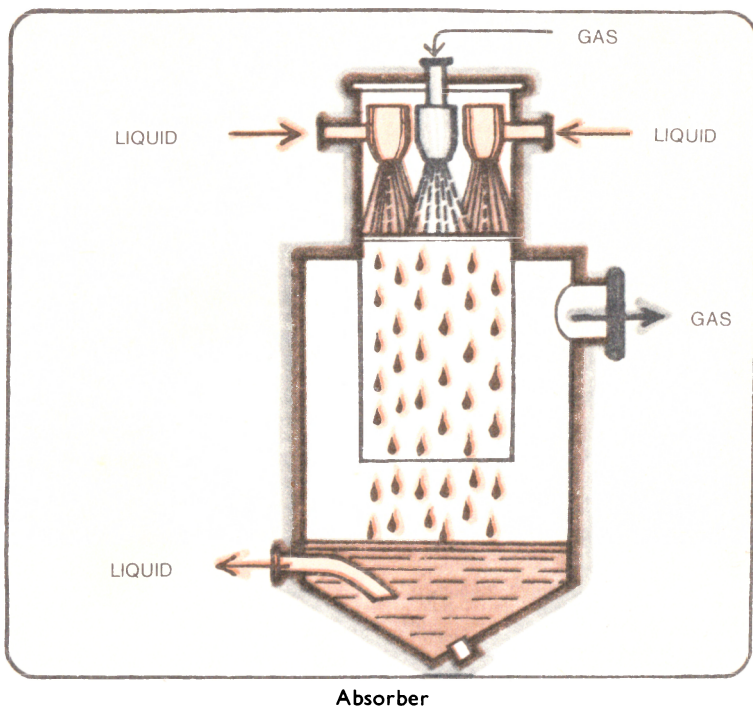
\* Partial pressure is the pressure a gas would exert if it alone were present above the liquid. Let us assume that the pressure of a mixture of gases is equal to 101 325 Pa (760 mm Hg) and that sulphur dioxide occupies 10% of the volume. Then its partial pressure would be 10 132 Pa (76 mm Hg).

very simply: the principle on which it works is based on the contact of gases with a liquid; two results are achieved by this: wet dust is precipitated by the increasing weight of the particles and the gases are absorbed. It is of interest to note that the designing of scrubbers for absorbing gases is much more dependable than for collecting dust. It is true that there are some small special features: when it is necessary to free the gases from dust particles, empty scrubbers are preferred; whereas when the main thing is to absorb gases, packed scrubbers (packed with ceramics, wooden racks etc.) are used. Besides, the absorbers are usually made of materials resistant to corrosion, for example, stainless steel.

For gas cleaning, use is also made of wet, high-speed (turbulent) dust collectors, providing the gases readily dissolve in the liquid used, because the duration of their contact is too short. The advantages that high-speed apparatus have when collecting dust, except for their small size, are not apparent in the case of absorption.

The second condition is the requisite driving force of absorption; it is maintained by circulating the absorbing liquid. As the liquid becomes saturated with the dissolved gaseous component, its absorptive power falls: the difference in concentration and the partial pressure is reduced, and as a result, the driving force decreases. To maintain the active state of the liquid it is necessary to withdraw it, completely, or partially, from the cycle and replace it by fresh liquid. And what about the contaminated absorbing liquid? It is heated to liberate the absorbed gas. Then the solution is cooled and returned to the absorber, and the liberated gas is utilized to obtain useful products. In some cases when the solid or wet products obtained after absorption are not used anywhere, they are disposed of in dumps where they are stored without causing any harm. That is what is done, in particular, when aqueous lime solutions or suspensions of ground limestone are used to extract sulphur dioxide. But in that case it is not absorption that takes place, but chemisorption, i.e., absorption of a gas by a liquid containing a substance that reacts with the gas.

Chemisorption, in other words, chemical cleaning of gases, is



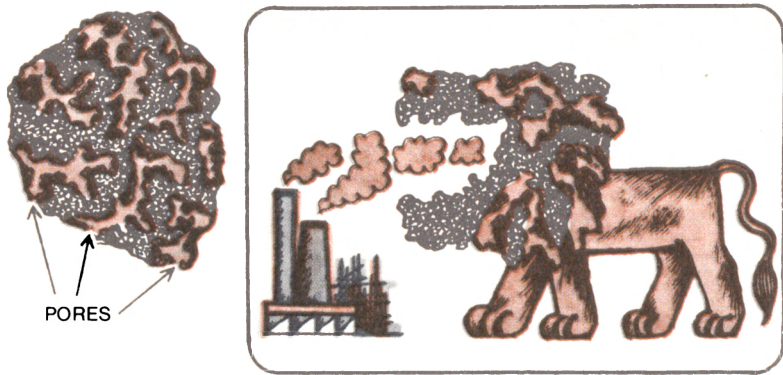
widely practiced in metallurgy. The advance of chemisorption over ordinary absorption lies in the fact that it forms stable compounds with the gas being absorbed, which simply cannot be formed by the other components of the gas mixture. The process is completely selective. Various reagents can be used: a sodium carbonate solution for hydrogen sulphide; aqueous alkali solutions for oxides of nitrogen; milk of lime and magnesium oxide for chlorine. The largest number of industrial chemisorption processes are those used for freeing the gases from sulphur dioxide. Most of them consist in first chemically combining the sulphur dioxide in some compound or other and then liberating it again by heating; only now it is

more concentrated and suitable for the production of sulphuric acid. Such, for example, are the ammonia and zinc processes. In the lime process, as we have already pointed out, the resulting compounds are stored in dumps. Who knows, maybe they will find some application in the future? Blast-furnace slag, as we know, is now used for preparing building materials (rubble for roads, blocks for wall panels, etc.) or as fertilizers. At the Azovstal Metallurgical Works such a waste-free production process exists. Beside metal, the plant produces annually about 3 million tons of blast-furnace slag from which are derived 800-850 thousand tons of granulated raw material for the manufacture of cement, about a million tons of pumice stone, 785 thousand tons of slag rubble, and up to 100 thousand tons of slag wool, for which purpose deposits of old dumps are reprocessed. Open-hearth slags are reprocessed to produce phosphate fertilizers. The plant makes quite a large profit from such production. Well, how do you like such wastes?

## **The Marvelous Lace**

World War I brought many disasters to mankind, but one of them alarmed the world. This was a new weapon—war gas (poisonous gases). An urgent need arose to find means for protection against it. The best and most competent scientists were mobilized for this purpose. So, in 1915 in the period when Germany began to use poisonous gases on the fronts, including the Russian, a successful means was found to render them harmless. The remarkable Russian chemist N. D. Zelinsky proposed the use of active carbon, thanks to its ability to absorb gases. That is how the gas mask appeared that saved the lives of many thousands of soldiers.

Already in 1771, that is two centuries before gas masks appeared, the well-known German chemist R. Sheele noticed that carbon, charcoal in particular, is capable of intensely adsorbing various gases. Since then adsorption, the taking up of gases on the surface of a solid, has been thoroughly studied in all its details. It was



Structure of a particle of activated carbon

found that not only carbon but other substances that occur widely in nature are good adsorbents. It is by adsorption that the soil is enriched by substances it needs; that green plants obtain carbon dioxide from the air.

In contrast to absorption, adsorption takes place on the surface of a solid, and both liquids and gases can be adsorbed. This is important because in adsorption of gases, as a result of capillary condensation, it may turn out that liquid molecules rather than gas molecules are adsorbed on the surface of the solid.

What special properties must a solid possess to be a good adsorbent? First of all it must be porous, i.e., have a well-developed texture—the finest lace, visible only under a microscope. Just like in absorption, the size of the pores (“traps”) must be commensurable with that of molecules. How is this achieved? In different ways, depending on the substance used. In order to purify metallurgical gases, use is made of active carbon, silica gel, zeolite, alumina and other substances.

Let us begin with active carbon. It is obtained from peat, brown coal, coal and wood charcoal, and even from nut shells and fruit stones. These materials are heated without access of air, to free

them from volatile matter and moisture, and are subsequently subjected to additional treatment: they are either oxidized by a gas or steam, or treated with chemical reagents. As a result, a lace-like (openwork) porous framework is obtained. The reason for using the smallest possible pores is not only that they are commensurable with molecules but that they increase the surface of contact with the gas. The greater the ratio of the surface of the body to its volume, the more active the contact becomes, and the better does adsorption proceed. The specific surface of active carbon is so great that it amounts to hundreds of thousands of square meters per kilogram of grains of this adsorbent. A hectare, a metric measure of area used in agriculture, is equal to only ten thousand square meters. While here in one kilogram there are several tens of hectares.

There are three kinds of pores in active carbon: micro-, meso- and macropores, i.e., small, intermediate and large pores. The latter do not play a significant part in adsorption—they are too large in comparison with molecules. Mesopores, those of intermediate size, serve mainly as transport arteries through which the gas that is adsorbed is conveyed to the micropores where the molecules are retained. It is here in the micropores that the interaction between the gas molecules and solid molecules takes place, to be more exact, between their fields of force. Of course, this process takes place in the intermediate pores too, but only close to the surface. Further adsorption can proceed on the adsorbed gas itself. The molecules cling to each other just like the dust particles in cloth filters. The lower the temperature, the more intense is adsorption. In this respect adsorption does not differ from absorption.

Active carbon is used for freeing gases from sulphur dioxide, and not only in metallurgy but in the chemical industry and in power engineering as well. Silicon-containing adsorbents such as silica gel and zeolite are used for this purpose too. Silica gel, an amorphous silica of varying composition, can be obtained by synthesis. It possesses great mechanical strength which makes it possible to reuse it many times. Silica gel is widely used for adsorbing and separating vapors of organic substances, for drying gases and

liquids, for purification and desulphurization of petroleum products and oils.

Zeolites – boiling stones – are wonderful adsorbents. They too can be of natural origin or produced by chemical synthesis. Why boiling? Because on heating they liberate adsorbed water. On cooling, readsorption of water takes place. The regular structure of zeolites is remarkable. Their skeleton consists of a framework with relatively large honeycomb (cellular) cavities which communicate with small inlets. The shape and size of the cavities, enormous in number, depend on the nature and composition of the zeolite (zeolites are a group of aluminosilicates of sodium, calcium and other metals). One gram of natural chabazite contains  $3 \times 10^{20}$  cavities. It is difficult to even comprehend this figure. 300 billion taken a billion times. Only molecules of a diameter less than the diameter of the inlet can penetrate into a cavity. Synthetic zeolites are manufactured with inlets of a diameter of 30, 40, 50, 80 and 90 nanometers (3, 4, 5, 8 and 9 angstroms).

Adsorption, both in the case of carbon and silicon-containing adsorbents, proceeds in the same way. First sulphur dioxide is taken up on the inner surface and in the micropores of the adsorbent. If the gas contains oxygen and water they are simultaneously adsorbed and react with the adsorbed sulphur dioxide to form sulphuric acid. Nitrogen molecules, the main diluent of the gases, do not penetrate into the pores. Such is the specific adsorption of carbon and silicon-containing adsorbents. The adsorbability of one or another substance depends on their molecular weight: the greater it is, the less is the chance that the molecules will enter and be retained in the pores.

The adsorption of toxic contaminants from gas mixtures is carried out in apparatus called adsorbers. The most widely used adsorber consists of a cylinder made of steel or some other material inside of which there is a perforated ceramic plate of many holes. In passing through them the gas is uniformly distributed over the cross section of the adsorber. A layer of gravel from 100 to 200 mm high is spread over the plate: first large grains, then smaller ones. A layer of carbon or some other adsorbent is placed atop. The



gases subjected to purification pass through this rigid bed.

Use is also made of adsorbers with a fluidized bed. Such a bed is produced by gases moving at a high speed, which cause the grains to be suspended: the grains occupy a considerable volume of the adsorber, as if floating in it. In a fluidized bed adsorption of gases takes place more intensely.

As the adsorbent is saturated with the gas, its activity is diminished and, just like in absorption, it becomes necessary to remove it for regeneration or to dump it somewhere. The regeneration of adsorbents is performed in several ways: hot gas or superheated steam is passed through the layer of saturated adsorbent. The temperature of the gas and steam must be high, otherwise the adsorbed gas will not be removed from the surface.

It is also possible to utilize the spent adsorbent that contains adsorbed gases. From this point of view, of interest is the process of cleaning gases in the electrolysis of aluminium. The adsorbent used is the alumina which will be electrolyzed to obtain aluminium. The gases from the electrolyzers, containing hydrogen fluoride, are fed by a gas blower into the reaction vessel with a fluidized bed of alumina. The hydrogen fluoride is adsorbed, and the alumina enriched by it is removed and conveyed to the electrolysis baths. The content of fluorine in the used up alumina is 1.26% instead of 0.008% when it was fresh.

Adsorption methods for cleaning gases were appreciably developed in the 50s of this century. Up to that time, liquid absorption was chiefly used, which still coexists with the dry methods because it has a number of advantages over them. An advantage of the dry processes is that they allow the gases to be cleaned at higher temperatures, and hot gases are readily dispersed in the atmosphere. Besides, the apparatus is not clogged up with dust and is not attacked by corrosion, and there is no waste water that has to be purified. .

## **How Long Will the Torches Burn?**

If you happen to be in the vicinity of an oil refinery your attention is certain to be drawn by fires flaming high above the ground. They are toxic gases, ejected during oil refining, that are being burned off. That is just how harmful components of metallurgical gases are gotten rid of, in particular, the carbon monoxide and tarry matter formed, for instance, in the electrolysis of aluminium. Subsequent burning is one of the means of chemical cleaning of gases. But it is not always the best way. In the first place, fuel is lost in vain—for if the gas burns it would be much better to use it as a fuel. In the second place, combustion products such as soot are formed, which pollute the environment and are bad for people. You have surely noticed how sticky pots get near gas stoves. So why do the torches burn?

In order to utilize the toxic gases their concentration must be high (which is not usually the case), just as it is practically impossible to utilize sulphur dioxide when its concentration in the gases is low. Perhaps at sometime in the future carbon monoxide or other harmful impurities of low concentrations may be put to profitable use, but in the meantime they have to be burned off.

Why did we refer to subsequent burning as a chemical method of gas cleaning? As a matter of fact, burning is nothing but oxidation. In this case, as in that of adsorption and absorption, we enlist the services of molecular interaction. Our assistant is oxygen which combines with the toxic impurities in the gases, oxidizing them to form harmless carbon dioxide and water vapor.

How are the harmful substances burned off? There are three ways, depending on the concentration of the toxic impurity to be burned. If its concentration is high enough, it is sufficient to mix it with the necessary amount of air and set it on fire. After that, burning continues by itself; as is said, the process becomes auto-genic. There is no need for supplying additional heat as the oxidation itself produces it. A single condition must be observed: the burners must be located high enough to protect the personnel and buildings from the flames and high temperature. In the USA,

for example, there are burners that are lifted to a height of 90 meters.

When the concentration of the impurities to be burned is low, the air and gases are mixed in a special chamber with a built-in burner for heating it. In it some fuel or other is burned, the temperature in the chamber rises and after that, as in the first case, the impurities start to burn. If heat is not supplied, however, combustion ceases. It is obvious that it is senseless to use the gaseous impurities as the fuel because they burn only if additional heat is provided. This method is used for rendering tarry matter harmless in the electrolysis of aluminium.

The third way, catalytic burning, is used when the concentration of the impurities to be removed is very small and when the process has to be activated or conducted at low temperatures. Metals or metallic compounds, such as platinum, cupric oxide, and manganese dioxide, can serve as the catalyzers. They are applied as a thin film on plates, balls or rings which are placed in the chamber or reaction vessel for burning. Catalytic burning is an essential participant in the processes of producing paints, treating foodstuffs, enameling, hardening foundry cores. When treating gases with a high content of organic matter, the catalyzer quickly becomes spoiled (contaminated). This happens, in particular, in the treatment of metallurgical gases; therefore, they are preferably burned directly. Catalytic burning is used to make the exhaust gases of automobiles harmless. In the future it is likely to be successfully used for freeing gases from oxides of nitrogen. In comparison with combustion, catalytic burning is a cheaper method.

For the present, subsequent burning of toxic impurities cannot be dispensed with; that is why the time has not come yet to extinguish the torches.



## ON THE WATCH

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### Inevitable Co-Travellers

How can we describe the cleaning of metallurgical gases in detail? You are already acquainted with dust collectors and what they are capable of, but it must be observed that metallurgists do not, by far, monopolize their use. Gas and dust collectors are used in many branches of industry. Just how are they utilized in metallurgy? This is a rather difficult question to answer. Metallurgists give the national economy several tens of different metals, almost all in the Periodic Table. Every metal has its own "character". Let us take, for example, the melting point—the temperatures vary over a range of three and a half thousand degrees. Tungsten melts at approximately  $3400^{\circ}\text{C}$ , while mercury solidifies at  $-38.9^{\circ}\text{C}$ . The raw materials from which the various metals are obtained are also different. There is a great variety of metallurgical plants. One and the same metal can be obtained in different ways. Steel, for example, is smelted in three basic types of plants: in open-hearth furnaces, in converters and in electric furnaces. There are as many ways of cleaning metallurgical gases as there are processes for obtaining metals, because the nature of the gases in each case is different and so is that of the dust in them. It should be added that the dust-collecting services do not confine themselves to any one apparatus in each particular case, but combine them in order to achieve the required degree of purification. And how great the number of combinations can be is well known from mathematics. It is practically impossible within the bounds of one book, all the more of a popular science book, to describe the technological processes for obtaining all the metals and all the methods of cleaning the ejected gases. But what if we limited the number of metals, showing preference to one over another, for instance to iron or steel, to copper or lead, nickel or aluminium and mercury? It is only just to ask why should one metal be preferred to another? Doesn't the production of each of them, and for that matter, of the rest of the metals require the services of dust collecting and gas

cleaning? Certainly, every one of them does. So what should we do not to "offend", for example, arsenic, antimony or tin?

We will have to try to solve this problem otherwise, approaching it from another angle, namely, from the point of view of environmental pollution control and the utilization of valuable wastes. What processes from this viewpoint demand great attention? How and to what degree do metallurgists cope with freeing the waste gases from dust and toxic impurities and recovering valuable substances from them? What are the future ways and means of improving the metallurgical processes and the technology of gas cleaning?

The answer to the last two questions will be found in the next section and now let us return to the metallurgical works producing copper. There, in roasting, reverberator and electric furnaces and converters, pure copper freed from the sulphur accompanying it is produced. In the flames of the furnace, the sulphur is burned out, forming sulphur dioxide. This is one of the toxic impurities that occurs most widely in the emitted gases. It is formed during the combustion of fuel and in the production of iron steel, lead and other metals. All metals are freed from sulphur; a relatively high content is admissible only in free-cutting steel, i. e., in steel that is to be machined on automatic metal-cutting lathes. In this case the chips have to be brittle, and sulphur reduces ductility. Just what is the toxic effect of sulphur dioxide? It is one of the gases that irritate the mucous membranes of the nose, throat and eyes. It sometimes causes emphysema and swelling of the throat and even paralysis of the respiratory tract. Sulphur dioxide converts green plantations to deserts, as we already know.

The gases emitted by plants of the iron and steel industry contain a considerable amount of carbon monoxide produced by incomplete combustion of carbon.

Another toxic gas is the oxides of nitrogen, the sources of which are metallurgical furnaces and combustion chambers. From the point of view of atmospheric pollution, this gas in recent years competes even with sulphur dioxide.

And, finally, fluorine. Very little can be compared with the harm-

ful effects it has on all living things. It primarily injures plants. In France, for example, the common pine tree disappeared within a radius of two kilometers around a plant that emitted fluorine. Fluorine destroys flowers and fruits and through them other living things. Bee keepers in some industrial regions in France have noted an increase in the death rate among bees poisoned by fluorine. There have been cases of reduced productivity and fertility of domestic animals which were fed with fodder containing fluorine. The source of atmospheric pollution by fluorine are, first of all, the plants producing aluminium. These plants can also emit carcinogens, in other words, substances that produce cancer, as for instance, 3,4-benzpyrene.

Not only gases harm the environment. Some metals are far from being harmless. For example, lead. The very same lead that affords protection against radiation and X-rays. The oxides of lead are very volatile. They are formed primarily in lead plants, but not only there. Ores of non-ferrous metals usually contain metallic impurities and lead is often present in them.

There is yet another metal—mercury. It can safely be said that it is as indispensable for the national economy as it is poisonous. History records a case of mass poisoning on the English ship *Triumph* in the year 1810, when mercury ran out of a leaking barrel.

These perhaps are the most toxic metallurgical impurities. We have only failed to mention dust. Any dust is very unfavorable for man and the environment. It gets into the respiratory tract; it screens the rays of the sun, covers green leaves with a dense film, thus restricting the intercourse between plants and the sun and therefore hindering photosynthesis; and, finally, it simply makes our homes dirty and adds work for housewives. No wonder the vacuum cleaner, a miniature cloth filter, has come to play an important part in our domestic life.

The toxic substances we have spoken of as well as dust are inevitable co-travellers of metallurgical processes and it is essential not to allow them to perform their “black deeds”. Then people will profit twofold—the environment will be protected and its wealth utilized to its full value.

## **In Step with the Times**

Cast iron and steel are alloys of iron and carbon. In ancient times they were substituted for bronze and ever since, as a constructive material, they have not resigned their priority in the competition for strength, durability and processability. The demand for iron and steel is constantly growing. The commissioning of new enterprises and new production processes poses new serious targets before the gas-cleaning services. It has been calculated that for each million of tons of steel produced in one year, 350 tons of dust, 200 tons of sulphur dioxide and 400 tons of carbon monoxide are ejected every day. Improvement of the metallurgical processes sometimes produces such changes in the quantity and quality of the dust and gas emissions that considerable changes in the means of gas cleaning are demanded. The best example of this is the development of blast-furnace metallurgy. It can be said that in the process of the struggle to cope with the emissions, new methods of gas cleaning were discovered.

At the beginning of the century metallurgists realized that the gases ejected from blast furnaces were valuable. They contain up to 30% of carbon monoxide which is a fuel, and fuels are always needed. In the initial state, however, blast-furnace gas causes trouble—dust clogs up the burners and the heating facilities that are warmed by the combustion products of the gas. It was necessary to clean it. But how? At that time only mechanical apparatus, dust chambers and cyclones, were available. Of course, that was crude cleaning, but still it was better than nothing. In those days the problem of air pollution was not so acute as it is now and even such means of cleaning were more or less adequate. But research was constantly conducted and very soon mechanical means were supplemented by wet dust collectors—scrubbers and rotary dust extractors. You already know about scrubbers, and as concerns rotary extractors, they have gone never to return; still they marked a new period in the development of dust collecting.

What was a rotary dust extractor like? It was something between a cyclone and a scrubber, consisting of ventilators on rotating wheels

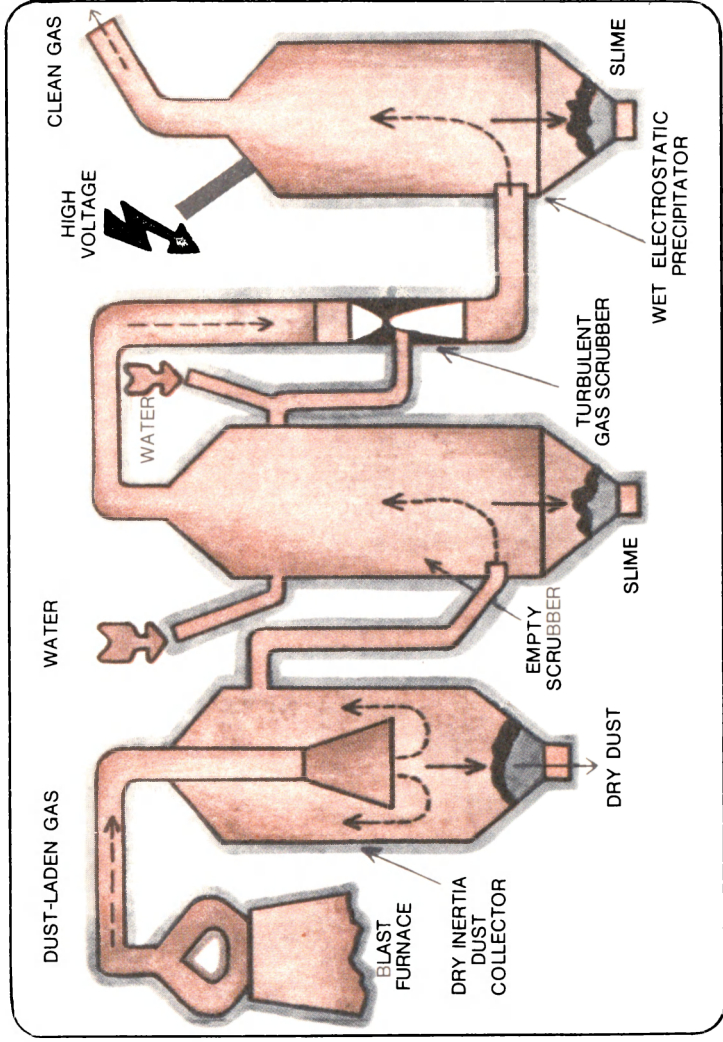


that supplied water. The heavy wet dust was ejected from the gas flow due to centrifugal force. Since the 30s, rotary dust extractors are no longer used. At about the same time there appeared in the iron and steel industry, as assistants to dust chambers and cyclones, cloth filters with woolen bags. Gas is freed of dust in them most efficiently, but the durability of wool, as you understand, is clearly insufficient to justify their use economically.

In that period, at the end of the 20s and the beginning of the 30s, wide-spread use was begun to be made of wet electrostatic precipitators, owing to a large extent to the efforts of Soviet researchers and designers. One would think that the story about dust collectors could come to an end here. But luckily that is not the case. This time it was the blast-furnace metallurgists who stepped forward.

When the Second World War was over, the Soviet Union urgently needed metal. Without it the national economy could not be restored. To accelerate the smelting process, blast furnaces were changed over to high-pressure blasting. The pressure of the outgoing gases also increased beneath the throat at the top of the furnace. The pressure must be reduced and for this purpose turbulent dust collectors, Venturi tubes, were put in the path of the gas flow; in some cases instead of Venturi tubes, a system of throttle valves was installed to decrease the pressure of the gas. This was accompanied by an increase in the speed of the gas in conjunction with the inflow of water into the Venturi tubes. Wet electrostatic precipitators were installed behind the Venturi tubes. That is how the modern system of cleaning blast-furnace gases originated: dry mechanical apparatus – turbulent gas scrubbers – wet electrostatic precipitators. This system assures a low dust content in the blast-furnace gases, less than  $10 \text{ mg/m}^3$ .

But apparently, the development of cleaning of blast-furnace gases has not come to an end. At the present time cloth filters, which almost "left the stage" in the 30s when the electrostatic precipitator appeared, are being used once more now that designers have at their disposal heat-resistant and acid-resistant synthetic fibers. Thus the development of dust cleaning in blast-furnace metallurgy, as imposed by the needs of production, proceeds in step with the times.



Flow diagram for cleaning of blast-furnace gas

## **A Matter of the Future**

Why do metallurgists insist on cleaning blast-furnace gas with such zeal? Well, the gas is needed for preparing the raw material for smelting in blast furnaces. These furnaces demand ore, limestone, coke and other materials, in lumps of a given size. In this respect they are very capricious. Large-sized materials are crushed, while small-sized materials are sintered (agglomerated). For this purpose, in the iron and steel industry, metallurgical works with a complete cycle always have sintering plants. Here, in fact, is "food" for the dust-collecting and gas-cleaning services. One third of the dust, 80% of the sulphur dioxide and over 60% of the carbon monoxide emitted by the ferrous metal industry come from the sintering plants. What takes place there? The prepared mixture of the furnace charge, i. e., the raw materials taken in definite proportions, are placed for sintering on a horizontal conveyer belt. Vacuum is maintained under the sections of the conveyer and from above it a firing mixture of blast-furnace and coke-oven gases is sucked through the layer of the charge. The gases pass through the charge, part of which is inevitably carried away with them because it is basically dust itself. By the way, the flue dust collected from blast-furnace gas is added to the charge.

Sintering dust contains 40-50% of iron. Why is the content so great? The fact is that sintering is simultaneously a physical and a chemical process. The charge is not only caked as a result of the high temperatures, but in these conditions the sulphur and carbon in the coke fines and other components of the charge are burned out. That is where the sulphur dioxide and carbon monoxide in the gases come from. And inasmuch as the content of sulphur and carbon is diminished, the content of iron is relatively increased.

What is the granulometric composition of sintering dust? It is comparatively coarse, mechanical (the temperatures are too low for the formation of sublimated dust). More than 80-90% of the dust particles are over 10  $\mu\text{m}$  in size. It is expedient in this case to collect such dust in mechanical apparatus. For a long time multicyclones were used for this purpose; but the amount of dust is very great and the diameter of each unit is small, which results in high hydraulic resistance and clog-

ging by dust. In short, in recent years these cyclones have been replaced by wet apparatus—scrubbers and Venturi tubes. But even that has not solved the problem of freeing sintering gases from dust.

The problem of freeing the gases evolved in sintering plants from noxious gases is not a simpler one. Apparatus using the limestone or magnesite process are provided for freeing the gases from sulphur dioxide; but as concerns the oxides of nitrogen and carbon monoxide, there are not as yet any methods for “trapping” them. That is a matter of the future.

### **Sources of Economy**

The interesting arithmetical computations in the book *Limits of Growth*, written by scientists from the Massachusetts Institute of Technology evoked heated discussions all over the world. They calculated how long the explored reserves of the most important natural resources will last, namely oil, coal, natural gas, and iron ore. According to their data, there is now on our planet 100 billion tons of iron in iron ore. This amount at the current rate of consumption should last for 240 years; and in case the explored reserves will increase five times and consumption will grow as expected, for 173 years. You must admit it is not such a long period of time. Only seven or eight generations—less than two centuries. These calculations, however, can be accepted only conditionally: natural resources are now extracted from the top layers of the Earth only. What do the deeper layers and the bottom of the sea promise? Nevertheless, these figures are a warning signal urging us to be economical. We often hear: “manufacture of thin-walled tubes”, “rolling with negative tolerances”, “designing of lightened constructions”. These are means of rational utilization of metal. However, the primary source of economy of metal is to be found at its “birth”.

Let us consider the manufacture of steel. It is smelted in open-hearth furnaces, converters and electric furnaces. In spite of the considerable difference in the construction of these plants, the processes occurring in them are essentially the same: the charge is smelted, brought to boil and the impurities burn out. And where there is boil-

ing, there is evaporation. Iron evaporates, forming oxides which on cooling are converted to dust—the ordinary process of formation of sublimated dust. But what a lot of iron this dust contains! Converter dust contains up to 90% of iron and its oxides. The dust produced in open-hearth and electric furnaces is not so rich in iron; still its amount is not less than that in the initial ore. To preserve this dust for repeated reduction would save millions of tons of iron ore. But is this an easy task?

Sublimated dust (fumes), as you already know, is highly dispersed. And the more vigorously the process proceeds, the greater is the degree of dispersion. That is what happened with open-hearth dust when, in order to increase the efficiency of the furnaces, they were changed over to oxygen blowing. Simultaneously the amount of dust ejected increased ten times and the temperature of the outgoing gases is now 600-700°C. Prior to being cleaned these gases are conveyed to a waste-heat boiler. After that the dust is collected in dry electrostatic precipitators or in Venturi tubes, the simple design and adequate efficiency of which have made them very popular, at least in the iron and steel industry.

Although 70% of steel in the Soviet Union is now produced by the open-hearth process and only 25% in converters, it can safely be said that in the future the balance will turn in favor of converter smelting. It became the rival of the open-hearth process in the middle of the 50s when oxygen began to be used in smelting and the quality of the steel was markedly improved. Smelting in converters is more vigorous than in open-hearth furnaces. Where oxygen comes in contact with the metal, the temperature rises up to 3000°C; the temperature of the flue gases is also incomparably higher than that in the open-hearth process. At the beginning of blowing it is 1250-1300°C and in the middle and at the end of blowing, as a result of vigorous chemical reactions, it rises to 1600-1700°C. And what about the dust? Half of the dust particles carried away are smaller than 0.5  $\mu\text{m}$  in size. Open-hearth dust consists mainly of particles smaller than 1  $\mu\text{m}$ —small enough, though larger than converter dust. But it is difficult to clean converter gases not only because the dust particles are so small. These gases contain 90% of carbon monoxide as the steel is ready before the carbon is

completely oxidized. Therefore, the first operation in cleaning the gases emitted from converters is to burn off the carbon monoxide. After that the gases are cooled in a waste-heat boiler and, finally, cleaned in Venturi tubes. Only after that do they cease to be hazardous for the environment.

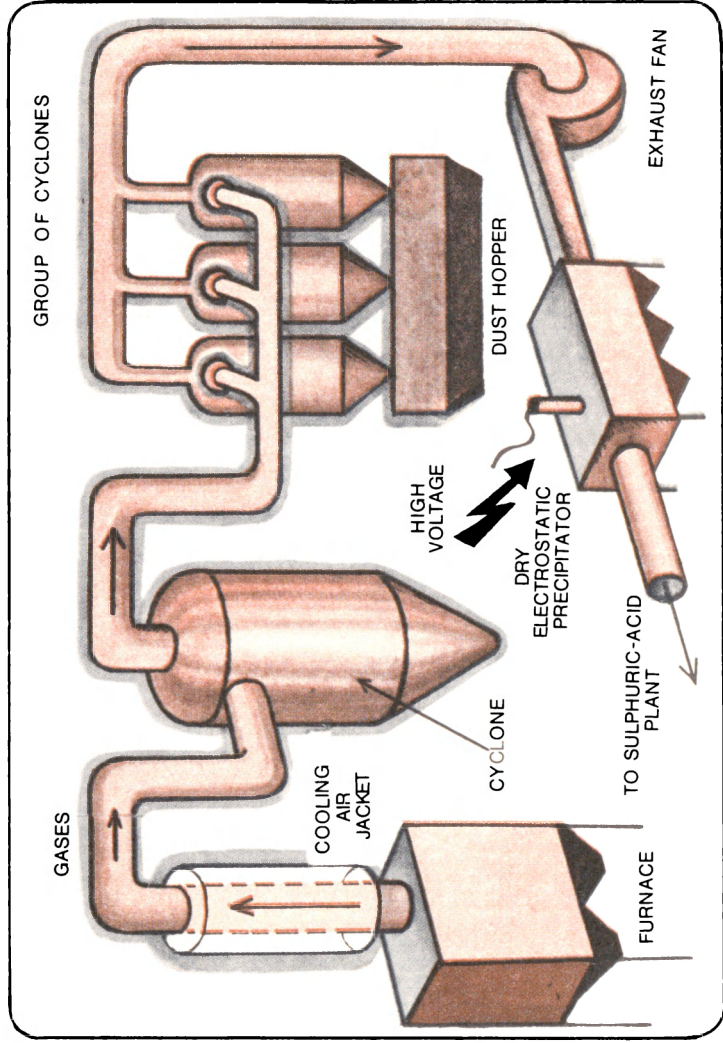
Other problems arise in the cleaning of gases evolved in electric furnaces. The construction of the furnaces is such that it is difficult to remove the gases from them. As yet there are two methods of drawing the gases off—either the furnace is completely covered with a hood under which the gases leave the furnace through leakages in the furnace or gaps at the electrodes; or an opening is provided in the furnace roof through which the gases pass into the uptake. The gases need not be cooled because under the hood or in front of the uptake they intermix with atmospheric air and cool down to 100-150°C. The gases increase in volume: when hoods are used, 10 to 15 times. A powerful ventilation system is therefore required to provide normal working conditions on the premises of electric steel-smelting plants.

The flow diagram for cleaning electric-furnace gases does not have a waste-heat boiler, but it usually includes three sets of wet-type dust collectors working in succession—a scrubber, Venturi tubes and cyclone drop collectors. With their aid it is possible to collect dust particles smaller than 0.7  $\mu\text{m}$ .

Thus, the struggle for economy begins at the very “birth” of steel.

## **Hand in Hand with Chemists**

If you should like to come into contact with chemists you need not necessarily go to a chemical plant; you can visit a metallurgical works. It is well-known that 30% of the sulphuric acid manufactured in the USSR is supplied by the non-ferrous metal industry, and sulphuric acid has always been one of the basic products of the chemical industry. Metallurgy and chemistry are closely interlinked in such copper-smelting works as those we spoke about at the beginning of the book. Then it was the amount of dust and toxic gases evolved there that interested us. Now we will tell you how these “undesirable fellow travellers” are dealt with.



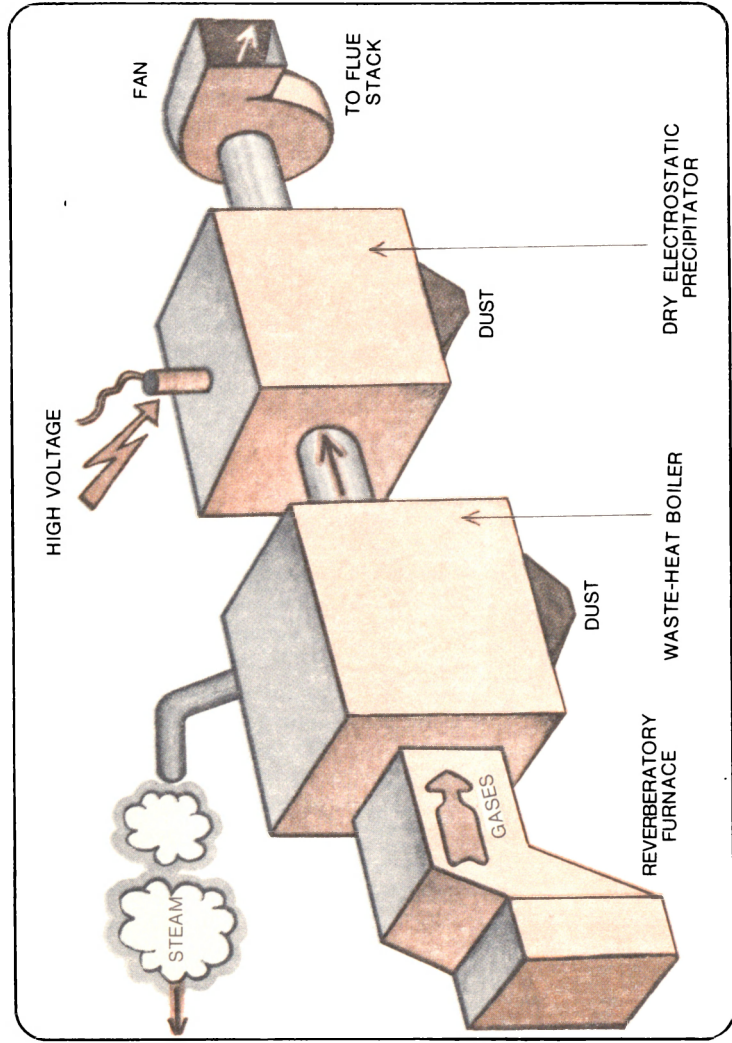
Flow diagram for cleaning gases of roasting fluidized-bed furnaces

At the present time, as you already know, because of the great amount of sulphur in copper sulphide ores, crude copper is obtained in three stages. You are familiar with the widely used technological flow diagram: roasting furnaces with fluidized beds, reverberatory furnaces, and converters.

In the roasting furnaces, compressed air is blown from below through a layer of finely crushed concentrate and the layer appears to boil. The particles in it are intermixed, ascending and descending like the balls in the hands of a skillful juggler. The air has free access to these particles and readily reacts with the sulphur in the ore, especially if the blown air is enriched with oxygen. This reaction forms very aggressive sulphur-bearing gases containing 13-15% of  $\text{SO}_2$ . Thus, the first stage in the manufacture of copper, the production of calcine, is also the first stage in producing raw material for the manufacture of sulphuric acid. But such continuous mixing of the concentrate in the furnace does not remain "unpunished"; in this metallurgical process a great part of the concentrate, sometimes up to 90%, escapes together with the gases, the temperature of which on leaving the furnace is 650-800°C. Hence, aggressive and high-temperature gases are evolved in the roasting furnaces. The dust in them varies in composition and particle size because copper ores almost always contain several metals including, besides copper, lead, zinc, arsenic and other metallic elements. Dust containing copper is large-size, mechanical. Copper compounds cannot be sublimated because the temperature in the roasting furnace is not high enough. But zinc, lead and arsenic are more easily melted and their compounds are volatile; that is why the dust containing these metals is sublimated. After roasting, the sulphur dioxide and all the different kinds of dust are practically converted to intermediate products which must be retained for further use and subjected to separation.

What means are used for this purpose? Sublimated dust (fumes) can only be collected in dry electrostatic precipitators because of the high temperatures and the aggressiveness of the gases. Of course, the gases have to be cooled, but not to a temperature lower than 300°C, otherwise condensation of sulphuric acid vapors can take place too early. At the same time, the oxides of sulphur in the gases serve, additionally,





Flow diagram for cleaning of reverberatory-furnace gases

to reduce the specific electrical resistance of the dust and thus to increase the efficiency of the electrostatic precipitators. The main thing is, however, that prior to converting these oxides into sulphuric acid they must be thoroughly freed from dust. They are conveyed to the sulphuric acid plant only after they pass through the electrostatic precipitators. The dust collected in the electrostatic precipitators contains lead, zinc, and arsenic.

The final stage of dust collecting is fine separation of the sublimates, preceded by coarse separation that is carried out in two-stage cyclones. In coarse cleaning the gases are freed of the copper compounds, which together with the calcine, go on to the reverberatory furnaces.

As you see, wet methods are not used in the manufacture of copper. That would require corrosion-resistant apparatus and neutralization of the acid return water.

The same means of dust collecting pertain to gases evolved in reverberatory furnaces. Some differences in the flow diagrams are due to differences in the dust content in these gases and in the content of sulphur dioxide in them. Whereas a cubic meter of the gas leaving roasting furnaces sometimes contains a kilogram and more of dust, the gases evolved in reverberatory smelting contain only 5-12 grams, i.e., a hundred times less. That is why cyclones are not installed—the electrostatic precipitators are quite adequate for cleaning the gases. Waste-heat boilers are used for cooling the gases. Unfortunately, the amount of  $\text{SO}_2$  in the gases given off in reverberatory smelting is not large enough for them to be sent to the sulphuric-acid plant—only 1-2% which escapes into the atmosphere. We have spoken of this before.

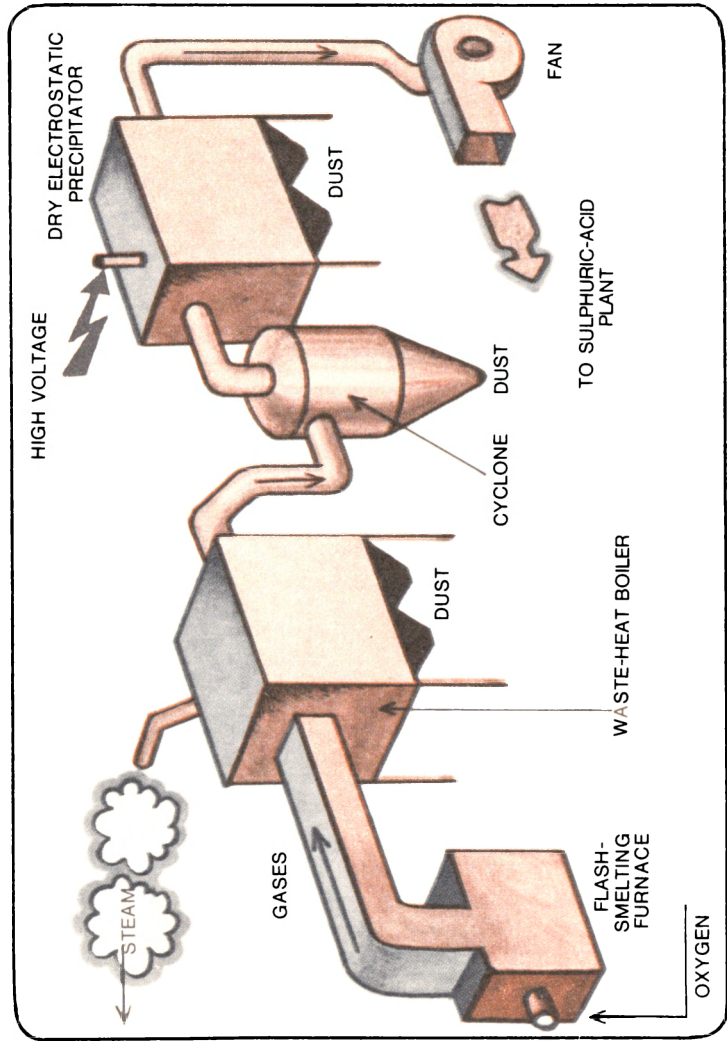
The dust content in converter gases is similar to that in reverberatory gases, but the flow diagram for cleaning them is somewhat more complicated. Why is this so? There are several reasons. First of all, the design of the apparatus. A converter is a barrel-shaped vessel with an outlet at the top for the escape of gases which are continuously evolved during blowing. They have to be brought together and directed into the flue. There are for this purpose so-called hoods that cover the converter outlet so that it is as airtight as possible. These hoods are connected through the flue

with dust chambers, cyclones, and at the end of the gas route, with dry electrostatic precipitators. Hence, once again, first the coarse dust is collected and then the fine dust, separating them from each other. The dust formed in converters is mainly fumes containing up to 50% of lead and 20% of zinc. The dust precipitated from the gases is sent to the corresponding plant. That is the second reason why the flow diagram is complicated. The third reason is that the gases have to be thoroughly cleaned to prepare them for the manufacture of sulphuric acid. The amount of  $\text{SO}_2$  in converter gases is quite sufficient for this: 5-12%.

The vulnerable spot in the reverberatory smelting process is the furnace gases themselves. Sulphur dioxide is ejected into the atmosphere and pollutes it, which is naturally undesirable. Because of the necessity of protecting the environment and utilizing the sulphur more completely, a new process for obtaining copper has appeared—flash smelting. Although less than two decades have passed since it appeared, it has fully proved its value. In flash smelting the copper concentrate is blown into the furnace by a jet of air or pure oxygen. Thanks to the large contact area between the concentrate and the oxygen, the sulphur is rapidly burned off. It can be said that the flash furnace performs the work of two furnaces: copper matte, the final product, is obtained by replacing roasting and smelting in a reverberatory furnace. The copper matte is then subjected to converting.

The gases of flash smelting are very rich in sulphur dioxide: when air blowing is employed, the amount of  $\text{SO}_2$  is 10-14%; when oxygen is used, 90%. Nearly all of the gases are this valuable semifinished product. In this country oxygen-flash smelting has been introduced at the Almalyk integrated mines and metallurgical works. The gases are cleaned in accordance with the following flow diagram: a waste-heat boiler, cyclones, and dry electrostatic precipitators. Then follows the production of sulphuric acid. Sulphur and liquid 100%-sulphuric anhydride can also be obtained from the gases of flash smelting which are rich in  $\text{SO}_2$ .

This is already pure chemistry. To produce sulphuric acid, the sulphur dioxide is passed through a catalyzer that accelerates its



Flow diagram for cleaning of oxygen flash-smelting gases

oxidation to  $\text{SO}_3$  which is then conveyed to absorbers. Sulphur trioxide on dissolving in water becomes sulphuric acid. Here in the process of manufacturing sulphuric acid, the gases are completely dedusted. Selenium, arsenic and other metallic impurities are also recovered from the gases. Thus, metallurgy and chemistry work hand in hand.

### **The Good and Evil Sides of the “Wing” Metal**

Metals do not come easily to man but some of them are more “obliging”, causing little trouble, while quite a lot of trouble has to be taken with others. Such, for example, is aluminium, the child of our electricity age. This metal is light and durable, is characterized by high thermal and electrical conductivity, and is not attacked by acids. It is often called the “wing” metal because it is indispensable to aviation. But only a specialist, watching an airliner soaring up into the sky, fully realizes what great difficulties are involved in the production of aluminium. The amount of electrical energy spent in producing one ton of this metal would be as much as one family needed during one and a half decades, if it were to use all the electric appliances available. That is rather expensive. But the high cost of aluminium is only part of the trouble: the main trouble is that its manufacture can cause irreparable harm to us and to our environment. The compounds of fluorine (fluorides) are indeed a great evil for nature!

As a matter of fact, aluminium is not easily obtained. Its manufacture consists of two practically independent processes: the preparation of alumina and the production of aluminium. Alumina is the trioxide of aluminium ( $\text{Al}_2\text{O}_3$ ). It is extracted from the following ores: bauxite, alumstone, and nepheline. They all contain the trioxide, but in different quantities. Bauxite contains up to 55%, nepheline 27%, alumstone a little over 20% of alumina. These ores differ also in that alumstone contains sulphuric anhydride, while nepheline contains almost all the ingredients needed to produce cement. That is why in the first case a large amount of sulphides

are thrown away, in the second it is necessary to organize cement plants. And cement plants are probably the chief source of dust: 400 thousand cubic meters of gas every hour, each cubic meter containing 30 grams of dust.

The production of alumina is so complicated and consists of so many operations that it is impossible to describe it briefly. The reader will have to take our word for it. From the point of view of dust collecting, of interest are the heating processes: the roasting of limestone (one of the components of the furnace charge, that is necessary for removing the silicon compounds); the sintering of the charge and calcination to draw off the water. Both sintering and calcination are carried out in tube furnaces at 1150-1200°C. The furnace emits up to 300 000 m<sup>3</sup> of gas an hour, and each cubic meter contains up to 150 g of dust; the calcining furnace, up to 72 000 m<sup>3</sup> of gas, i.e., four times less, but this gas contains four times as much dust.

Substantial figures, even difficult to comprehend at once. Simple arithmetical calculations show that the smelting furnace emits up to 45 tons of dust an hour—the capacity of 10 dump trucks. How is the dust evolved in the production of alumina collected? The sintering gases in modern plants are cleaned in two stages. Their temperature is 300°C. At first the gases are directed to multiclones, then to four-field dry electrostatic precipitators. The total proportion of dust collected equals 99.0-99.9%. The gases after cleaning contain 0.1-0.2 gram of dust per cubic meter.

The calcining-furnace gases are practically cleaned in the same manner, the only difference being that the multiclones are installed above the furnaces and the dust returns by gravity to the furnaces. The total amount of dust retained by the entire dust-cleaning system is equal to 99.5%.

The ventilation gases drawn off by the suction system are adequately cleaned in one stage in horizontal dry electrostatic precipitators; as a result of cleaning there remains 0.1-0.15 gram of dust per cubic meter.

To obtain alumina is only half the job. It is still necessary to

extract aluminium from it. It is extracted in large rectangular metal boxes lined with carbon plates. This is what the electrolysis cell are like: the bottom of the cell constitutes the negative electrode (cathode); carbon rods immersed into the cell serve as the positive electrodes (anodes). They are connected with the power supply through busbars. The current passes from the anodes through the alumina dissolved in a layer of molten cryolite to the cathode. As the current passes, the alumina is decomposed and is reduced to aluminium. A layer of liquid metal collects on the bottom of the box. At first glance everything seems simple enough.

What makes it so complicated? Let us begin with the special features of electrolyzers. The first is where the busbars are introduced. To electrodes located at the top of the bath, the current is supplied from the top or from the side, i.e., baths can be top- or side-supplied. This difference is essential in dust collecting for several reasons. Another possible difference is the kind of anodes used. They can be self-baking by means of the heat generated in the bath or preliminarily roasted in special apparatus. And that is not less important for dust cleaning than the different ways of current supply.

The current on passing through the electrolyte generates in the cell high temperatures at which many chemical reactions proceed. Gases bearing dust and toxic impurities are vigorously liberated at the anodes. The dust contains alumina and cryolite. The particle sizes vary over a great range: they can be smaller than  $1\text{ }\mu\text{m}$  and as large as  $50\text{ }\mu\text{m}$ . And what about the gases? They contain hydrogen fluoride and carbon monoxide and tar. Where do they come from?

The source of hydrogen fluoride is cryolite without which the electrolysis is impossible. Alumina free of water is a highly heat-resisting oxide that melts at a temperature of  $2050^{\circ}\text{C}$ . Such a temperature is not easily attained in the electrolysis cell. It was found that alumina readily dissolves in cryolite and, moreover, for the electrolysis of this mixture it is sufficient to heat the cell to a temperature of  $950^{\circ}\text{C}$ . The use of cryolite makes the process of producing aluminium much less costly. To reject cryolite would mean to reduce the manufacture of aluminium and that is out of

the question. So we have to protect ourselves against hydrogen fluoride the best we can.

The carbon monoxide results from the burning of the anodes which are made of petroleum coke and other materials containing carbon and tarry matter. A carcinogenic substance (3,4-benzpyrene) contained in the tar escapes together with the gases. By the way, tarry matter is emitted only in electrolyzers with self-baking anodes. As a matter of fact the essence of preliminary baking consists in the removal of tarry matter. The temperature of the anode gases varies from 50 to 150°C.

The concentration of gaseous impurities and aerosols in the anode gases depends on the type of electrolyzer, the kind of anodes, and the method of charging the alumina. The greatest amount of dust and gases is formed in electrolyzers with top current-supply and self-baking anodes; the least amount, when roasted anodes are used.

For each kind of current supply a special type of cell cover is used to draw off the liberated gases which would otherwise become "unorganized", escaping into the air.

Electrolyzers in which busses enter from the top are provided with a gas collector in the form of a bell. The effectiveness of gas collecting in this case is not very high—only 60-70%. The rest of the gases escapes into the shop. These electrolyzers are additionally provided with burners for the combustion of the carbon monoxide and tar. The gases are cleaned in two steps: first they are freed from dust and tar in two-field electrostatic precipitators and then they are sprayed with a sodium carbonate solution in empty scrubbers. As a result of this, 97-98% of the hydrogen fluoride, 90-95% of the dust, and 60% of the tar is collected.

In electrolyzers in which the current is supplied from the side, the gases are collected by means of louvers. Their efficiency is 80-90%. In this case use is made of two variants of two-stage flow diagrams: a dry electrostatic precipitator and an empty scrubber; or an empty scrubber and a scrubber with floating packing of small hollow plastic balls which continually contact each other and in this way are freed from the deposits on them, primarily from sticky tar. In



the second variant 99.5% of the fluorine and 92% of the dust are removed.

It is easier to clean the gases evolved in electrolyzers with preroasted anodes. From 85 to 95% of the liberated gases are removed by means of louvers. They are cleaned in two steps: at first in vertical electrostatic precipitators, then in scrubbers. The dust is collected in an amount equal to 92%, hydrogen fluoride 96-97%.

All the flow diagrams described above include wet apparatus. This is necessary for eliminating the hydrogen fluoride. As elsewhere the disadvantages of the wet method are manifested here too. Therefore, in recent years a dry method based on adsorption of the hydrogen fluoride by alumina has been introduced. We have already spoken of this (see p. 113). In this method approximately 99% of the hydrogen fluoride and dust is adsorbed.

Nevertheless, in the production of aluminium, the dust-cleaning service still faces many problems. The effectiveness of freeing the gases from dust and fluorine is as yet inadequate. Large quantities of gases even fail to get into the covers of the electrolyzers and penetrate into the shops. These gases, through openings in the roof (skylights), are drawn away from the working places but are ejected into the atmosphere. You must admit that it is not the best way of dealing with them. The cleaning of skylight gases involves great difficulties due to the amount of gases and to the complications that arise when using wet apparatus at low temperatures in the wintertime. All these problems are being worked on and will, without fail, be solved, and then we will speak only of the good sides of the wing metal.

## **A Multiple Solution**

For comprehending the dual problem of environmental protection and rational utilization of natural resources, it is hard to find a better model than the manufacture of lead.

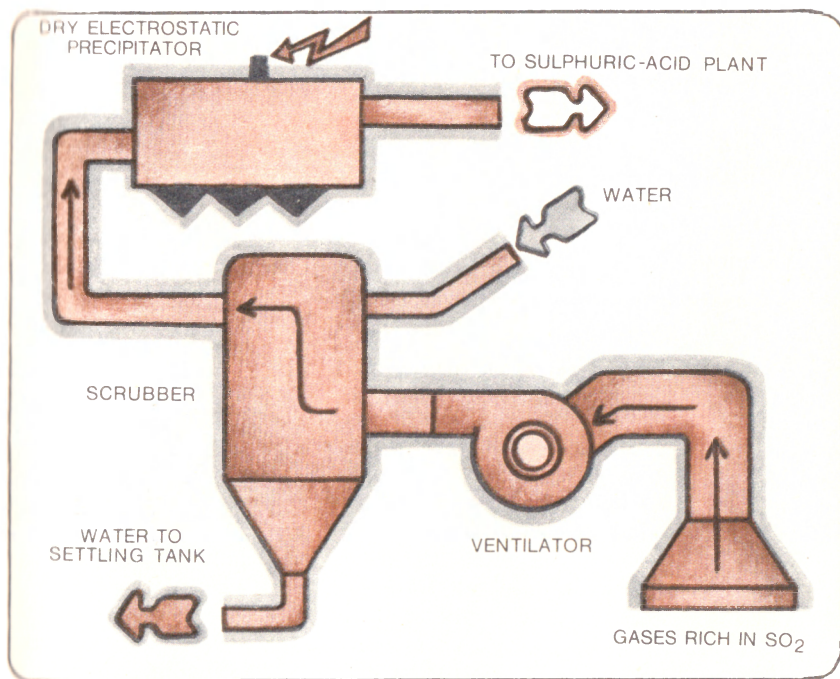
Lead gives as much trouble to the dust-cleaning service as copper and aluminium do. However, if in the production of copper harm is

caused mainly by sulphur dioxide, and in the production of aluminium by hydrogen fluoride, in the case of lead it is the metal itself that is harmful. History has recorded many "crimes" committed by this metal. Some American toxicologists claim, for example, that lead poisoning was the reason for the untimely death of Roman patricians who used dishware set in lead. It is hard to say whether this is true, but as a matter of fact, the remains of ancient Romans actually do contain lead. In large concentrations, lead causes acute poisoning; in relatively small concentrations, chronic poisoning. This is inferred from the content of lead in the blood, which incidentally is higher in persons who live in urban areas than in those who live in rural areas. This is due to the lead exhausted by motor transport. This also constitutes one of the problems of environmental protection.

If lead is so poisonous, obviously the main task of dust collecting in lead production is to prevent the metal from getting into the atmosphere. This task is not an easy one, because lead oxides are volatile (fumes) and yield highly dispersed dust. Cloth filters are the most reliable barrier against them, all the more so because the temperatures of the gases after they leave the metallurgical plants are relatively low and considerable cooling is not needed. Another thing in favor of employing cloth filters is the comparatively low content of sulphurous anhydride in the gases.

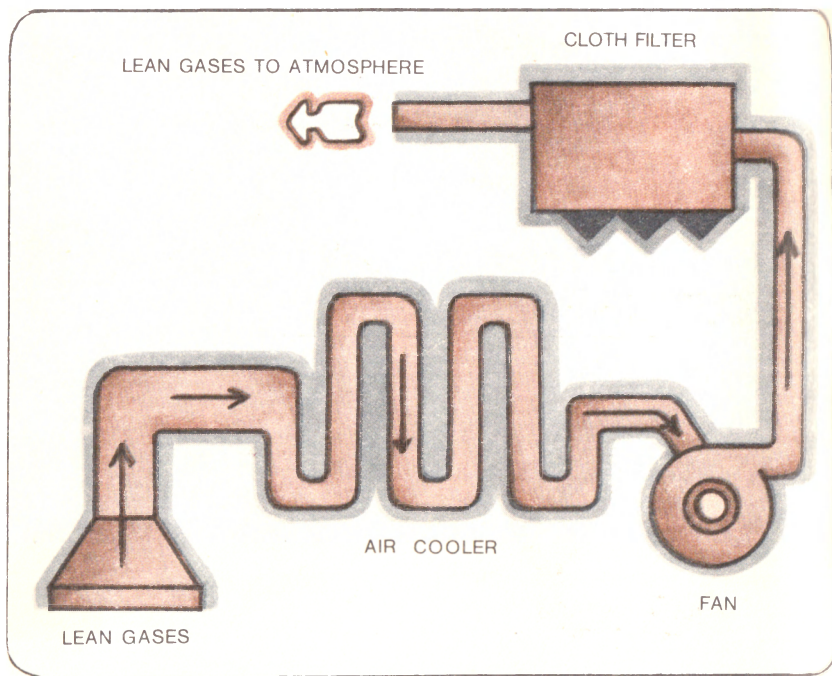
The raw material from which lead is obtained is ores that, like those of copper, contain sulphur. As the content of sulphur in lead ores is half as much as that in copper ores (only 20%), they are freed from sulphur in two stages: the first of them is sintering, the second smelting in shaft furnaces, with coke added for reducing the lead oxides to lead.

And where there's sulphur, there's sulphur dioxide. How much? Process gases with a high sulphur content are evolved only in one plant – the sintering machine (which also evolves lean gases). The point is that in lead plants, sintering is carried out in two ways: either an air blast is turned on from the bottom (updraft sintering) or air is sucked through from the top (downdraft sintering). The first method is the more effective one. In this case, the top of the machine is covered with a hood, the space under which is separated (conditionally) into



Flow diagram for cleaning of sintering gases at lead plants: for gases

two zones from which the rich and lean gases are withdrawn separately. Gases rich in sulphur dioxide (5-6%) issue from the head of the machine; while lean gases (1-2%), from the tail end. Owing to such a design, it is possible to utilize part of the sulphur dioxide; the rich gases are sent to the sulphuric-acid plant. This is the first step in solving the problem of utilizing natural resources. The lean gases have to be ejected into the atmosphere. Attempts made to recycle the sulphur dioxide (by returning it, together with the air blast, into the head of the



rich in  $\text{SO}_2$  (on the left); for lean gases (on the right)

machine) did not bring about the desired result. The gases formed in a sintering machine where air is sucked through from above and in shaft furnaces, just like the above lean gases, are also ejected into the atmosphere. The concentration of sulphur dioxide in the process gases of these plants is not over 1.5%.

It is the sulphur-dioxide content that determines what dust-collecting apparatus is chosen. Electrostatic precipitators are used for cleaning the rich gases emitted from sintering machines. The gases are preliminarily moistened in scrubbers in order to reduce the dust electrical

resistance. After leaving the electrostatic precipitators, the gases are sent to the sulphuric-acid plant.

As lean gases do not injure fabric, their fine cleaning is carried out with the aid of cloth filters. For coarse cleaning use is made of cyclones after which the gases are cooled in air-blown shell-and-tube coolers. The process gases ejected from sintering machines where air is sucked downwards are dedusted in a similar manner; cooling, however, is not included in the flow diagram because here it is unnecessary.

The gases from shaft furnaces are cleaned consecutively in cyclones, empty scrubbers and cloth filters. The fumes of lead are collected very effectively in cloth filters. The gases leaving the dust-cleaning apparatus contain only 20-30 mg of dust per cubic meter of gas.

At lead plants, great attention is also paid to cleaning ventilation gases. Coarse cleaning alone proved to be insufficient, as too much lead gets into the atmosphere. Therefore, taking into account the large amount of ventilation gases and the relatively low initial content of dust in them, bag filters with jet reverse blowing are now widely used at lead plants.

The dust generated in the production of lead is a valuable raw material containing many different metals. Besides lead and zinc, the dust also contains cadmium, indium, selenium, tellurium, thallium and other metals (the content of these metals in the dust is 10 to 20 times greater than in the ore concentrates). Till recently, the dust formed in the production of lead was returned to the sintering charge and only lead was extracted from it. Now it is treated separately to obtain the valuable components in it.

The slag formed in the manufacture of lead is very rich in metals. Approximately 60% of the germanium, up to 80% of the indium and 20% of the thallium go over into it. Besides that, 80% of the zinc and 20% of the copper also pass over into the slag. Therefore, it is subjected to additional treatment. The slag is fumed, i.e., an air-coal mixture or a mixture of natural gas and air is blown through it. In the process of fuming, 90-94% of the zinc and 95-98% of the lead is extracted from the slag. At the same time indium, tin, cadmium, germanium are also extracted from it. Since the temperature in the furnace rises to

1350°C, the reduced metals evaporate, are then oxidized once again above the bath and are carried away as dust by the furnace gases. Bag filters are used to collect this dust, too.

Thus, the dust-collecting service recovers raw materials and solves the problem of environmental protection.

### **Using All Available Means**

That mercury is highly poisonous we know from childhood, ever since grown-ups anxiously guarded us against the silvery-white drops scattered on the floor when we broke a thermometer. The disastrous effect it has is so great that in the USSR and other countries it is strictly against the law to employ mercury in some production processes, for example, for preparing paints. But mercury is necessary for industry and must therefore be produced. What do metallurgists have to do not to bring disaster to man? Mercury must on no account be ejected into the atmosphere or discarded with waste water. All the physical and chemical means available to the dust-collecting and gas-cleaning services must be mobilized to protect the environment.

The metallurgical process of extracting mercury from its ore, cinnibar ( $\text{HgS}$ ), is relatively simple. The ore is either roasted in tube furnaces fired by natural gas or oil, or in fluidized-bed furnaces. The mercury is sublimated and passes off with the gases, while the sulphur in the ore is burned to form sulphur dioxide.

The gases containing mercury vapors emitted from the furnace are freed from dust, first in different cyclones (including multiclones) and then in dry electrostatic precipitators. Whereas the content of dust in the gases leaving the cyclones is  $3 \text{ g/m}^3$ , it is reduced to  $0.2\text{--}0.3 \text{ g/m}^3$  in the gases leaving the electrostatic precipitators.

The purified gases are cooled in tube condensers. On cooling, the mercury vapors condense and liquid metallic mercury mixed with dust is collected in drip pans. Naturally, the more thoroughly the gases are dedusted before cooling, the smaller is the content of dust in the mercury and the easier it is to free the mercury from dust in the subsequent operations.

When the gases leave the condenser they contain 5-8 times less mer-

cury than after they leave the electrostatic precipitators: all in all, 25-80 mg/m<sup>3</sup>.

But even such a concentration of mercury is too high. Here adsorption and absorption prove helpful. The adsorbents used include, for example, activated carbon, pretreated with chlorine, and manganese oxides. Absorbents of mercury include the solutions of some acids and alkalis, bleaching powder and also aqueous suspensions of pyrolusite (crude MnO<sub>2</sub>), and activated carbon. Gaseous chlorine, for instance, is also an active absorbent of mercury. What is the result? After cleaning, usually 0.1-3 mg of mercury per cubic meter of the gases. That is not so bad.

Thus, by using all the available means of protection, it is possible to reduce environmental pollution by mercury to a minimum.





## A LOOK AT THE FUTURE

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### Air of the Highest Quality

Have we the right to speak so of air? Is it a commodity manufactured by man and not one of the fundamental elements of nature? Can we define it in Standards? As a matter of fact we not only can do so, but must do so. It is by no mere chance that the atmospheres of other planets are investigated first of all when searching for living beings. In ancient times when life first appeared on the Earth its atmosphere was favorable for supporting life. What has happened since then? The Slovak book *Civilization's Trojan Horse* (see additional reading) has a very apt title reflecting the reverse side of man's activities. Civilization bringing such enormous progress to mankind has changed nature to such an extent that our very life is under threat of extinction. In any case, on our planet in places inhabited by people, there is no longer any primeval clean air. And the reason for this is the activity of man—at first domestic (hearths and ovens) and then industrial. The atmosphere began to be polluted by impurities. At first they were the products of combustion of fuel—both solid ash, dust, soot, and gaseous carbon dioxide and sulphur dioxide. As far back as the middle ages the inhabitants of the British Isles experienced discomfort from the combustion of coal and the countless number of fireplaces in their homes. With the passage of time more people began to suffer from smoke and now all of mankind, especially people who live in large cities. In the last 100 years, according to data issued by the United Nations, the population of the globe has doubled, while the population of cities has grown five times. And the greater the city, the greater the air pollution. For example, in the USA the content of dust in the air of large and small cities was found to be, in micrograms (a millionth part of a gram) per cubic meter: in Chicago 183.4, in Philadelphia 155.5, in Honolulu (the capital of Hawaii) 38.7, in Cheyenne 33.7. And in the famous Grand Canyon, a national park, only 18.5, apparently due to the numerous cars of the crowds of tourists who come there.

Things have come to such a pass that in big cities fresh air has become such a scarcity that it became necessary to set up automatic machines for dispensing oxygen, as in Tokyo, for example. But this service is not available everywhere although it ought to be—to all and at all times. That means standards on the quality of air are needed to specify, in particular, limitations for industries that emit harmful substances into the atmosphere. Such limitations are the maximum permissible concentrations (MPC) of pollutants in the atmosphere.

Soviet hygienists played an important part in working out methods and choosing criteria for the determination of MPC. In 1949 these criteria were published for the first time, with no precedent anywhere in the world. It was proposed that the maximum permissible concentrations of pollutants should be considered those that cannot be exceeded without directly or indirectly harmfully affecting the human organism, i.e., reducing a person's ability to work, adversely influencing his health or mood. Adaptation of the organism only proves that the concentrations involved are inadmissible. The adverse effects of pollutants on plants, the climate, clearness of the atmosphere and domestic conditions of the population are likewise qualified.

There are three ways of approaching MPC—hygienic, sanitary and technological. The first is concerned with biological comfort, the second makes allowances for technical and economical feasibility, and the third is based on the necessity of preventing the ejection of valuable components.

Naturally, only the first approach is truly humane. Neither man nor nature (animals and plants) should be adversely affected by civilization. Such a hygienic approach is the one adopted by the socialist countries. The maximum permissible concentrations are determined by many tests in which the remote effect of one or another harmful substance is ascertained. In other countries, in particular, in the FRG and the USA, the approach is sanitary. There it is based on the immediate danger threatening the well-being of people and animals rather than observations and experiments carried on during a long period of time. Thus, for

instance, in California a system of smog alarms has been decreed. But even alarm No. 1 is proclaimed at concentrations of carbon, sulphur dioxide and oxides of nitrogen 20 times greater than the respective MPC in the Soviet Union. However in recent years these countries have also begun to use the methodology adopted in the USSR, due to the drastic effects of air pollution.

At the present time, in such countries as the USA, England, the FRG and Sweden laws are in force that are aimed at protecting the environment, in particular, the air and water.

In the USSR the first maximum permissible concentrations for ten of the most frequently occurring pollutants were established in 1951. In the following years the first norms were revised and experiments were carried out to determine MPC for 122 substances and 25 combinations of substances that are found in the atmosphere. Up to 1963 the USSR was the only country where there existed nation-wide standards for air quality. In 1963 a committee of experts of the World Public Health Organization proposed rules for establishing standards for clean air. Air quality was subdivided into four classes—from harmless (class I) to lethal (class-IV), urging all countries to strive to achieve the first class.

Is it sufficient, however, to specify MPC for particular pollutants and their combinations to settle the problems of environmental protection at the present time? There can be only one answer to this question. No, it is not. Now only multiple investigations of the effect of many factors on all the components of the environment can be adequate. The result of such studies should be the working out of the maximum permissible ecological stress.

The climatic conditions of particular industrial areas, the variety and large number of plants working simultaneously have made it imperative to find means of controlling their ejections coordinately. The search for these means have resulted in the determination of such a standard as the maximum permissible concentration of ejection (MPE). In the USSR, from the year 1980 the rules and regulations for determining the MPE are stipulated in the standard "Environmental Protection. Atmosphere".

What is included in these rules and regulations? The

consideration of the many factors that affect the pollution of the atmosphere. The point is that for each industrial plant or other source of pollution, account is taken not only of its own ejections but also of those from all sources of pollution in the city or populated areas, including auto transport. The future development of the plant is also considered. The total sum of ejections must not exceed the maximum concentration (in the near-ground atmosphere) of substances harmful to the population, the vegetable and animal world. If, at the present time, a given plant is not capable of attaining the MPE, it is allowed to reduce its ejections in stages. Temporarily approved amounts of ejections are stipulated for each stage. The degree of temporarily permissible ejections is determined by that of similar plants with an optimum technology.

The geographical and climatic conditions in a given locality, the situation of dwelling blocks and parks (zones of rest) play a role that is of no small importance. In those cases when certain plants cannot eliminate or reduce their harmful ejections, a fixed time is set for withdrawing such plants beyond the limits of populated areas or for substituting their production by a non-polluting one or for organizing a health-safety zone.

Naturally, in zones of health resorts, in places where sanatoriums are situated, the specifications for MPC and of temporarily approved ejections are stricter. Thus, the standard specifies a multiple approach in establishing the maximum permissible ejections. Such an approach makes sure that anybody, whether he lives in a rural or urban area, will breathe air of the highest quality.

## **Waste-Free Metallurgy**

Science claims that an ideal production process is one that is waste-free, i.e., the less waste, the more perfect the process. This applies all the more to metallurgy where the wastes are very numerous and amount to millions of tons. The wastes include slag, slimes, waste water and (the subject of our book) gases and dust.

You may well ask, can they be avoided or are they unfortunately absolutely necessary? Science maintains that they can be avoided

and that the way to do it is to perfect the technology, the ideal way being metallurgy without wastes: a closed cycle in which all the ingredients of the raw material and all the by-products are utilized, and on the premises of metallurgical works fruit orchards serenely bloom and bear fruit. Is it a dream? As yet, it is. Unfortunately, there is much that we do not know and cannot do yet. Here is an example. The Ural metal ores contain from 30 to 40 different metallic elements, but for the time being we can only extract 22 of them. The rest are waste. But even that is already an achievement. Formerly the amount of valuable elements wasted was still greater. The amount of dust and gas emissions has also appreciably decreased thanks to the introduction of new technological processes and the improvement of dust-collecting and gas-cleaning apparatus.

What trends are now observed in improving the technological processes? Research is being carried out in many directions. First of all, hydrometallurgy, the extraction of metals with the aid of liquids, is gaining a foothold. The number of purely hydrometallurgical processes is very small as yet. In many cases, preliminary operations are still required for preparing the furnace charge (calcination, sintering), that are conducted by ordinary "hot" methods. But the substitution of even one pyrometallurgical process by a "liquid" one has a considerable effect from the point of view of environmental protection. This is so notwithstanding the necessity of clearing and neutralizing the waste water. At the present time more than 60% of zinc is obtained by means of hydrometallurgy.

At the Nadezhdinsk plant of the Norilsk group of mines and metallurgical plants a hydraulic process for treating copper and nickel concentrates has recently been successfully organized. In this process elemental sulphur, a very valuable product, is extracted from the concentrates.

The hydrometallurgical method can be used to extract valuable components from the dust which is formed in pyrometallurgical plants.

Another way of drawing waste-free metallurgy nearer is to make use of oxygen. Pyrometallurgical processes are always based on the combustion of either fuel or the inflammable substances in the raw

material itself, for example, sulphur. Otherwise how would high temperatures be attained? But combustion requires oxygen. Air which contains oxygen can be used. But only one fifth of the air consists of oxygen; the rest is ballast nitrogen. That is why it is more expedient to supply the plants with oxygen-enriched air or with commercial oxygen containing 90% of  $O_2$ . The consumption of commercial oxygen will be almost five times less than that of air.

At first oxygen was used to raise the working temperatures, to intensify the technological processes and to increase the capacity of the plants. But the advantage turned out to be threefold. Not only did production in the narrow sense profit by it; the emission of gases was reduced (less nitrogen was introduced into the plant); and correspondingly, the concentration of useful constituents in them was increased. An example of this is oxygen-flash smelting in which the concentration of sulphur dioxide reaches 90% and it is no longer a waste product as in reverberatory smelting, but a valuable raw material.

There is still another trend—electrothermics, otherwise called electric smelting. The metallurgical process is conducted in furnaces in which the heat is produced by electrical energy rather than by hot gases, the combustion products of some fuel. In short, here the amount of gases is minimal, as is the ejection of dust from the furnaces.

And, finally, the last trend is a decrease in the number of metallurgical process stages. It can be said that namely this trend can be the prototype of future metallurgy. Such a technology consists in the direct reduction of iron, in other words, the combination of the blast-furnace and steel-smelting processes. A plant that will work on the principle of direct reduction is already built in the region of the Kursk magnetic anomaly in Sary Oskol. Here no coke will be produced, nor will there be blast furnaces, open-hearth furnaces or converters. There will only be furnaces for direct reduction and electric furnaces. Instead of coke the reducing agent used will be converted natural gas containing 90% of carbon monoxide and 10% of hydrogen. The gas on passing through the heating devices will

walls of the collecting electrodes (also tubes) is decreased. This made an increase in the field intensity possible. Electrostatic precipitators with such electrodes, installed in a sulphuric-acid plant of medium capacity, effect substantial savings in capital investments alone.

Just as in the case of cloth filters, the temperature of the gases being cleaned by electrostatic precipitators will also be raised to 700-900°C, although the selection of materials for such high temperatures presents great difficulties. Heat-resistant steel is needed. The size and capacity of electrostatic precipitators are constantly being increased.

Both future cloth filters and electrostatic precipitators should draw us nearer to a waste-free technology, the reality of which is constantly affirmed by scientists at conferences and symposiums.

## **Economical Aspects**

Let us now "take stock" of the aforesaid. So, future metallurgy, notwithstanding growth in production, must guarantee clean air conforming to sanitary and hygienic specifications. In the future there will be great improvement in the technology of the metallurgical processes themselves and that of gas cleaning and dust collecting. Both demand considerable capital investments. This poses the question whether gas-cleaning construction may make the enterprise unprofitable.

Only economists can answer this question. In this respect the investigations conducted by the Sumy branch of the Kharkov Polytechnic are of interest. The Sumy economists considered every aspect of air pollution and showed that the economic losses due to air pollution cost much more than clean air.

Indeed, the cost of clean air consists only of the sums spent on constructing and operating dust and gas collectors. These sums are quite large, but the damage caused by air pollution is enormous. It involves losses in all the spheres of the national economy.

In the first place it is people who suffer from atmospheric pollutions because their health is endangered. It is impossible to evaluate the spiritual losses sustained, but it is rather easy to determine the cost of medical treatment in terms of money.

Public utilities are also greatly affected. People who live in cities know how often it is necessary to paint the outside of houses and repair roofs corroded by acid rains.

Agriculture suffers from a decrease in fertility of the live-stock and in crop yields. For example, in areas where there are emissions of aggressive gases and dust, the wheat crops are diminished by 40-60%, and the protein content in the wheat by 25-35%. Forestry is also affected.

The industrial losses are countless because of the rapid wear of equipment and the waste of valuable raw materials. That is characteristic, in particular, of metallurgy; a large part of the metallic impurities in the raw material pass over into the dust. In the production of lead such impurities are bismuth, cadmium and other metallic elements; in the production of copper-selenium, lead, zinc, rhenium. Moreover, large amounts of rare metals accumulate in the dust exceeding their content in the concentrates. A real treasure, isn't it? But it is difficult to extract this treasure and it costs a lot of money. At the present time, in all countries, non-ferrous metallurgical plants where pyrometallurgical technology is employed, spend about 20% of their total capital investments on collecting coarse and sublimated dust. Even more is spent in such processes as slag fuming and treatment of raw materials in rotary kilns. In these cases the cost of gas and dust collecting facilities is quite comparable with the cost of the metallurgical plants themselves.

The capital investments and expenditures depend on the technology used at a given works, the amount of gases cleaned, the physical and chemical properties of the gases and dust. Thus the process of freeing gases from coarse dust in cyclones or other mechanical apparatus is cheaper than dust collecting in more complicated apparatus (electrostatic precipitators, cloth filters). In electrostatic precipitators, for equal volumes of gas, the capital



investments are 7-10 times greater and the operating costs 4-5 times greater than those in cyclones. It should be taken into account, however, that in cyclones and other mechanical apparatus it is coarse dust of small value (in fact, the starting material) that is collected, whereas in electrostatic precipitators it is very valuable sublimates, the price of which fully justifies the cost of installing and operating apparatus for fine dust collecting.

But the question may arise whether, as a result of the high sanitary and hygienic specifications, gas and dust collecting would become so complicated that no recovered "treasure" could pay the costs involved. This, however, is simply impossible because a reduction in the damage caused by environmental pollution is always profitable.

Towards the end of the 70s, measures were taken to improve the sanitary conditions of the ocean of air in the vicinity of the Central Ural copper-smelting works. Of course, capital investments were necessary. First of all, a health-protection zone was organized and from the areas that were most polluted four thousand people were moved for whom houses were built elsewhere. Second of all, the manufacture of sulphuric acid was increased to utilize the sulphur dioxide, which also demanded an outlay of capital. In the third place, in the converters the flues and gas-cleaning system were reconstructed. As a result of these measures the emission of sulphur dioxide was reduced by 25 000 t a year, i.e., the loss of valuable raw material was diminished and the emission of dust into the atmosphere was reduced by more than 7 500 t a year. Taking into account the capital investments and annual operating costs (and also the profits from additional production and the reduction in losses sustained) the annual profit amounted to more than a million and a half rubles. These calculations were made for the works by the Sumy economists.

The Sumy scientists and economists also calculated the profit that would be obtained by substituting converter smelting by oxygen-flash smelting at the same works. Yearly the gain amounted to about 14 million rubles, 4 million of which are due to the reduction in damages caused to the environment.

The reduction in these damages is such an important factor that the Sumy economists suggested it to be the basis for controlling air quality and determining the maximum permissible ejections. And they not only proposed this, but introduced this factor in their calculations. They determined the maximum permissible ejections for a number of metallurgical works in the non-ferrous metal industry in several Soviet cities. In the automatized system for controlling atmospheric pollution, the predicted value (in rubles) of damage sustained was taken as the criterion for controlling the amount of emissions and regulating the traffic.

So, as we see, the cost of polluted air is not less, but even more than that of clean air and its high cost can serve as a stimulus for developing not only new manufacturing processes, but also new dust collectors and automatic systems for controlling air quality.

### **Computers on the Watch**

We are now approaching the end of our narrative. It only remains to speak about the constant vigilant monitoring that is necessary to assure high air quality. It will be recalled that the meteorological service is charged with controlling air pollution, but even a million of meteorologists could not cope with this task if they were not equipped with up-to-date facilities based on electronics. Computers have come to the aid of the human mind. They are the heart of automatic monitoring systems which collect data, process them and signal any deviations from standard specifications. Man need only make appropriate decisions in time. Today computers are used in industry and communications, in trade, in transport and agriculture. Meteorology is no exception.

The automatic system of monitoring air quality consists, in principle, of the following: a network of automatic stations distributed so that they completely cover the district under control. Each station determines several physical and chemical characteristics of the environment. The measurements are made by special transducers. Their signals are transmitted to a master station provided with a computer having a specific set of

programmes. If an emergency should arise, it assumes control of all the units of the system and warning of the control services. The air samples are analyzed in stationary and mobile laboratories. An automatic monitoring system of this type has been elaborated in the Soviet Union by the Voeikov Central Geophysical Observatory. Such systems can function within the limits of one city (a large city, of course, otherwise it would not be expedient to use one) or a whole region.

The data utilized to estimate the extent of air pollution include the concentration of the pollutants and the meteorological conditions: the speed and direction of the wind, the temperature and humidity of the air, the presence of clouds and fogs, i.e., factors that, if unfavorably combined, could give rise to hazardous atmospheric pollution. In case of danger, the necessary measures are taken: one fuel is substituted by another, additional cleaning apparatus is put into service, faulty motor vehicles are stopped, etc.

All that has been said refers to local control, the monitoring of air quality in limited areas. However, that is only part of the environmental-protection work carried on by the meteorological service with the aid of computers. This service, of course, is not confined to one city or region. Data from more than six thousand observation points located throughout the USSR are compiled in Obninsk, a city in the environs of Moscow. It possesses a center for collecting, processing, accumulating, retrieving and distributing meteorological data. Scientists and engineers began working on this automatic system in 1960. With its aid numerous investigations of the natural environment are now being conducted and weather forecasts are made daily. It is hardly necessary to emphasize the great significance of weather forecasts for the national economy, especially for agriculture and aviation.

Computer facilities help solve other, even greater problems. We have already pointed out that there are no frontiers for pollutants. That is understood by nations all over the world. Therefore, in 1972, in accordance with a decision of the UNO Stockholm conference on environmental protection, a Global Monitoring System was established. Its task is to monitor the biosphere, to

analyze its state and reveal any noticeable changes in it due to the influence of man's activities; without this, cooperation of man with the environment will become impossible. The following factors are determined: the composition of aerosols, the turbidity of the atmosphere, the chemical composition of rainfalls, the total content of ozone in the atmosphere, the concentration of carbon monoxide, and many other factors. The results obtained are sent to the world center for collecting global data in Ashville (USA). In the Soviet Union, monitoring of air pollution is carried out in the Caucasus and in the Syktyvkar, Irkutsk, Kaunas, Turukhansk and Kurgan regions. The data obtained is used to study the effects of industrial activities on the chemical composition of various components of the environment, to reveal how hazardous chemical substances are spread over a wide area, to investigate the effect of pollutants on ecological systems, the possible effect on the climate and much more.

Are there any other, future ways of making use of computers for environmental-protection purposes? Yes, there are. It is true that as yet they are confined to theoretical elaborations, but it is quite possible that they will be realized in the future. What we have in mind is modeling the environment and man's activities on an electronic computer, considering the biosphere in mathematical terms. The ultimate aim of this system is to achieve a closed cycle. It is believed that if funds were unlimited, scientists would be able to find control criteria suitable for this purpose.

And so, my dear readers, the narrative has come to an end, but efforts to prevent air pollution are still continuing and will continue further. Although you know how great the extent of atmospheric pollution caused by technological progress is, the future is not bleak. Do not be under the impression that you will have to live under a dim hazy sky. That is what we tried to tell you in our book and we will be glad if you have understood that the sky will be blue!













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